

ADVANCED GaAs MONOLITHIC 20 GHz RF SWITCH MATRIX

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FORWARD

This is the final report for contract NAS3-24895 with NASA Lewis Research Center, "Advanced GaAs Monolithic 20GHz RF Switch Matrix", covering the period from April 28, 1986 to April 27, 1988.

Dr. D.R. Ch'en was the principal investigator for this effort, and was responsible for the fabrication of the RF Switch Matrix.

Dr. W.C. Petersen was responsible for design and characterization of the switch matrix, and Mr. W.M. Kiba was responsible for assembly and packaging. Mr. G. Fujikawa was the NASA technical monitor for the entire activity.

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1) INTRODUCTION

A switch matrix is used in communications systems to dynamically route signals to their end destination. Advanced 30/20 GHz satellite systems technology spearheaded by NASA utilizes Time Domain Multiple Access (TDMA) techniques to further enhance functionality but necessitates spaceborne switching centers with up to 100 X 100 crosspoints. Switching at RF frequencies, as opposed to intermediate frequency switching, could eliminate much of the on-satellite RF electronics associated with up/down converters, their power supplies, and control electronics. However, at RF frequencies, current switch matrix technology was heretofore incapable of meeting the stringent signal isolation and high speed switching requirements. Microwave Monolithics Incorporated (MMInc.) has therefore developed a proprietary monolithic GaAs 20 GHz switch matrix design, fabrication, and packaging concept capable of meeting (with further refinement) systems goals for spaceborne applications. This report describes the results of a program to demonstrate proof of concept (POC) for such a systems approach via the design and fabrication of a 3 X 3 monolithic GaAs RF switch matrix.

MMInc.'s novel approach to monolithic 20 GHz RF crosspoint switching provides: 1) 0 dB insertion loss for 100 X 100 or larger spaceborne arrays 2) 55 dB or more isolation between input and output lines, 3) Higher reliability, 4) Potentially lower cost, and 5) Compatibility with advanced packaging techniques for spaceborne and ground applications. In this second phase of a multi-phase program, MMInc. has finalized the crosspoint design generated in program phase I and constructed and delivered a 3 X 3 matrix for experimental evaluation. This matrix was extensively characterized, culminating in the design and layout of a 10 X 10 matrix suitable for cascading into large RF switch matrix systems components.

Section 2 of this report provides an executive summary of the work performed under this program. Monolithic GaAs 20 GHz RF switch matrix design is described in detail in section 3, and fabrication of the complex monolithic subsystem and the unique package is described in

section 4. Various performance measurements are presented in section 5, with measured performance of the 3 X 3 20GHz RF switch matrix delivered to NASA Lewis Research Center summarized in Appendix A. Design of a 10 X 10 monolithic GaAs 20 GHz RF switch matrix complete with predicted performance is presented in section 6, followed by conclusions and recommendations for further work in section 7.

2) EXECUTIVE SUMMARY

NASA Lewis Research Center is spearheading the development of advanced technology satellite communications systems based on Time Domain Multiple Access (TDMA) technology. A cornerstone of this advanced technology is placement of complex signal processing and data routing on the communications satellite for optimum systems performance. Of the many technical challenges presented by this advanced systems architecture, perhaps most demanding is the design and implementation of the switch matrix. 10,000 crosspoints are required for full implementation of the 100 X 100 switch matrix envisioned by NASA, necessitating the use of light weight, physically small, high reliability crosspoints which meet the stringent systems performance goals. Following extensive theoretical and experimental evaluation of advanced hybrid implementations, several independent sources^(1,2) came to the unanimous conclusion that GaAs monolithic integration was the only viable implementation which could meet both the performance and physical requirements of the communications system. However a viable GaAs Monolithic Microwave Integrated Circuit (MMIC) approach was not identified.

Microwave Monolithics Incorporated (MMI Inc.) has developed a proprietary fabrication and packaging technology which could potentially meet the performance goals based on direct switching at the RF band. Substantial systems enhancements and cost reductions for advanced 30/20 GHz high data rate communications satellites is anticipated from both operation at RF frequencies and a compact, reliable, light weight, and low cost monolithic implementation. Program risks associated with the development of a space qualifiable 20 GHz RF switch matrix are, however, higher than those associated with IF switch matrix technology. A satellite systems trade-off analysis between the two approaches (which are not necessarily exclusive) requires a detailed understanding of the potential benefits and risks associated with each approach. Therefore, during program phase I, a study and design effort was implemented to acquire the required technical information necessary to assess the feasibility of an advanced monolithic RF switch matrix technology for application to communications satellites at 20 GHz. This was

accomplished, and during the current phase II program this design was finalized, a 3 X 3 switch matrix was fabricated, characterized, and delivered to NASA.

The objective of this phase of the multi phase program was to prove MMInc.'s concept of a monolithic GaAs switch matrix and its architecture by fabricating and characterizing the monolithic GaAs 3 X 3 20GHz RF switch matrix. Performance goals for this VLSI scale 3 X 3 switch matrix included 0 dB insertion loss to allow cascading into larger arrays, 60 dB minimum crosspoint isolation, and a maximum VSWR of 2:1 in a 50 ohm system over the 17.7 to 20.2 GHz RF band. At the conclusion of the program, the custom MMIC chip/package assembly would be delivered to NASA Lewis Research Center for data correlation and possible test bed integration. Design and simulation of a 10 X 10 monolithic 20 GHz RF switch matrix concluded the program.

All of these objectives have been met. The 3 X 3 switch matrix design was finalized, a mask tool set layout generated, and the mask tool set was procured. Characterization of a single crosspoint from this mask provided anticipated performance, with insertion loss of 4 dB (including 1 dB fixture losses) and isolation limited by the test fixture rather than the actual monolithic MMIC switching network.

It was anticipated, and rapidly became clear, that a major hurdle in this program would be to obtain sufficient number of VLSI scale chips to optimize the device and packaging technology sufficiently to fabricate a fully functional 3 X 3 20GHz RF switch matrix. None the less, based on the experience gained during a previous IF switch matrix development effort, a number of partially functional 3 X 3 switch matrices were successfully assembled and characterized in a timely fashion. Based on these initial results, processing and fabrication techniques were modified and optimized, ultimately leading to a fully functional 3 X 3 20GHz RF switch matrix. Measured performance for some of the 33,792 possible combinations of RF ports and matrix control settings are shown in Figure 2.1. As shown in these figures performance is well within program goals with the exception of insertion loss and

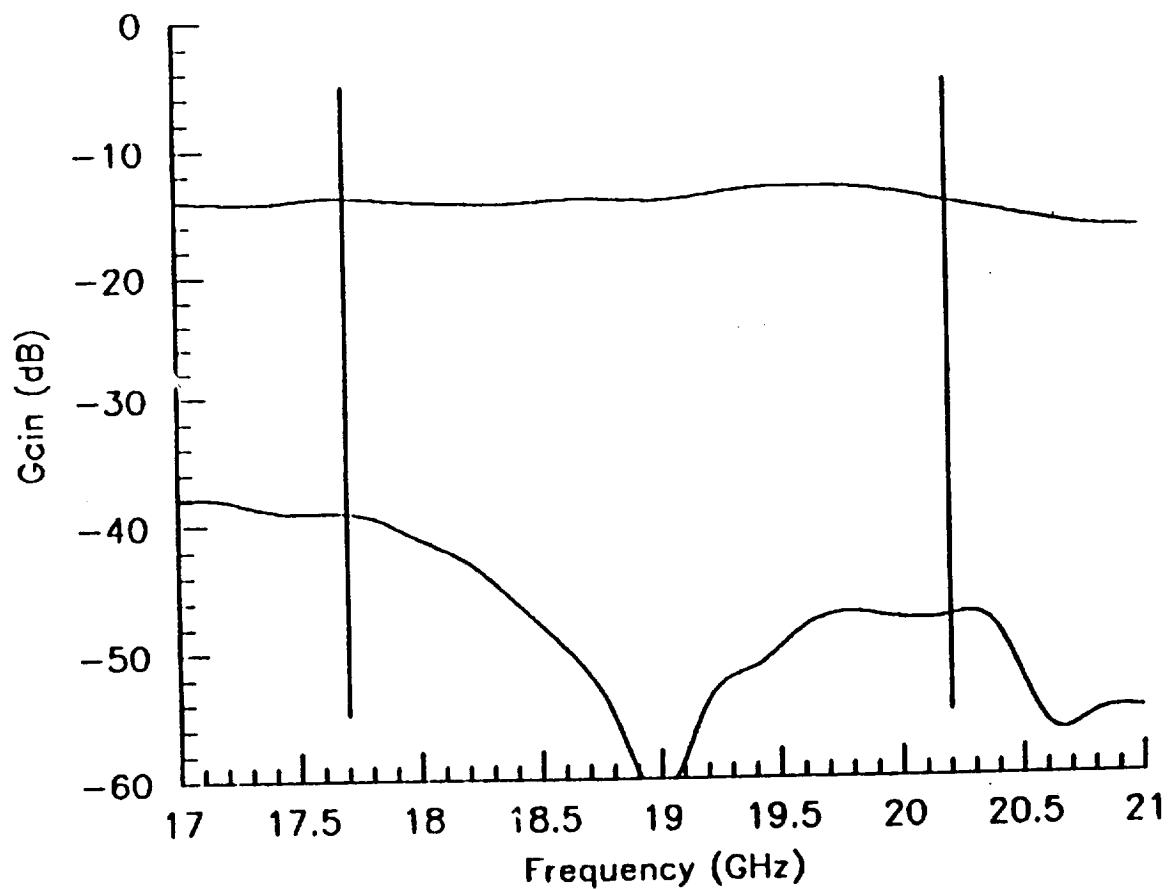


Figure 2.1a) Typical Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix without Buffer Amplifiers

1a

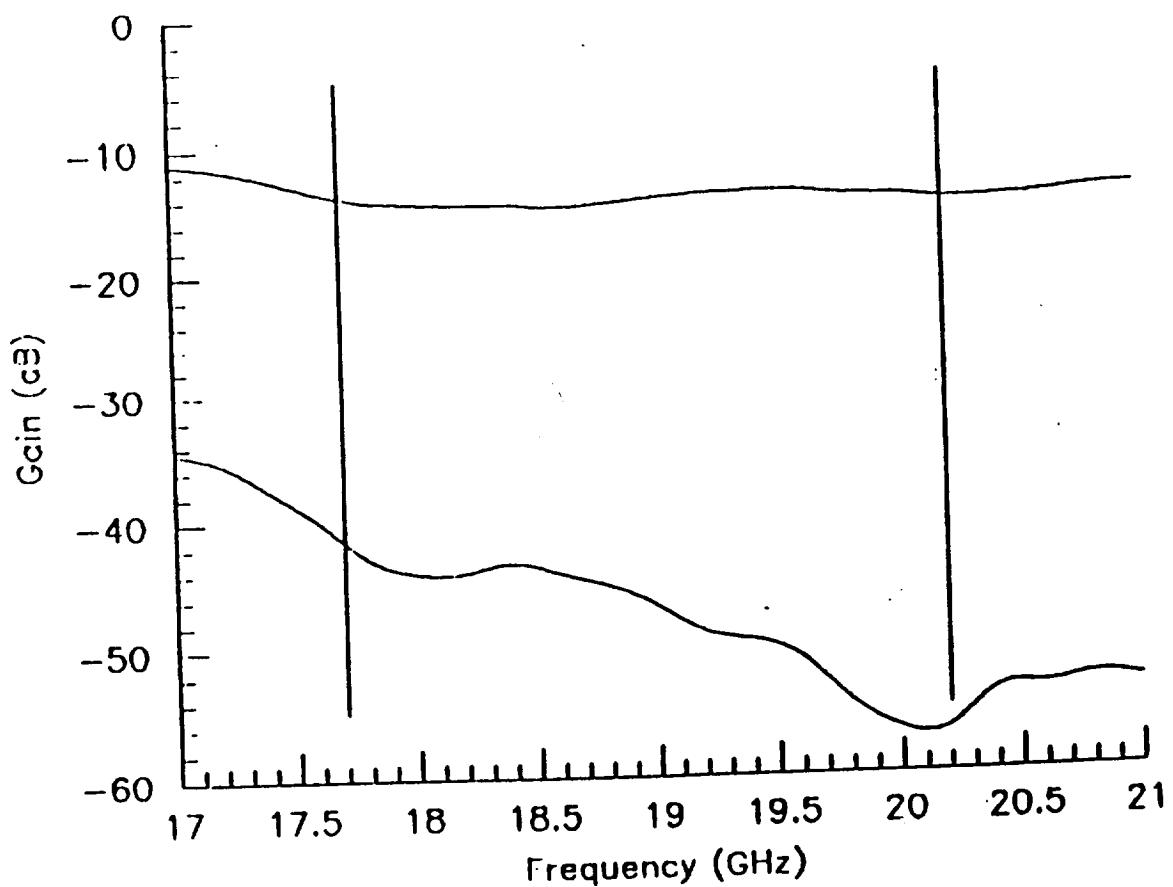


Figure 2.1b) Typical Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix without Buffer Amplifiers

isolation. The buffer amplifiers, not included in these preliminary assemblies, would correct for the insertion loss. The isolation limiting mechanism was traced to the control and signal bonding ribbons between the high isolation package and the high isolation MMIC chip. A modification of this interface, which was beyond the scope of this program phase, would be needed to circumvent this parasitic coupling path and attain the isolation inherent in the switch matrix design.

Power consumption, critical for spaceborne applications, is nearly negligible for these switch matrices. Only 3.7 milliwatts is required for operation of the full 3 X 3 switch matrix, with only slight increases occurring for high speed TDMA operation. This scales to just 42 milliwatts for a 10 X 10 matrix and 4.2 watts for a full 100 X 100 array. Naturally the buffer amplifiers would add to this total.

Due to the extensive effort required to fabricate a fully functional monolithic GaAs 3 X 3 20GHz RF switch matrix and the high risk associated with integration of the buffer amplifiers (which had never been done before), technical direction from NASA indicated that further integration should not be attempted until a second fully functional unit became available. That did not occur within program constraints, therefore the fully functional 3 X 3 switch matrix was delivered to NASA Lewis Research Center without integral buffer amplifiers. Six buffer amplifiers in individual housings were, however, delivered for external connection. A photograph of this monolithic GaAs 20 GHz RF switch matrix and the separately packaged buffer amplifiers is shown in Figure 2.2.

The full set of measured data for the delivered 3 X 3 20GHz RF switch matrix and the six buffer amplifiers is presented in Appendix A of this report. These measurements were made possible with a Matrix Switch Control Box designed and fabricated by NASA Lewis Research Center. This control box was extensively utilized in the final characterization stages of the program. Projected performance of the combined switch matrix / buffer amplifier subsystem is summarized in Figure 2.3, where all 9 "on" and the 9 "off" states associated with the

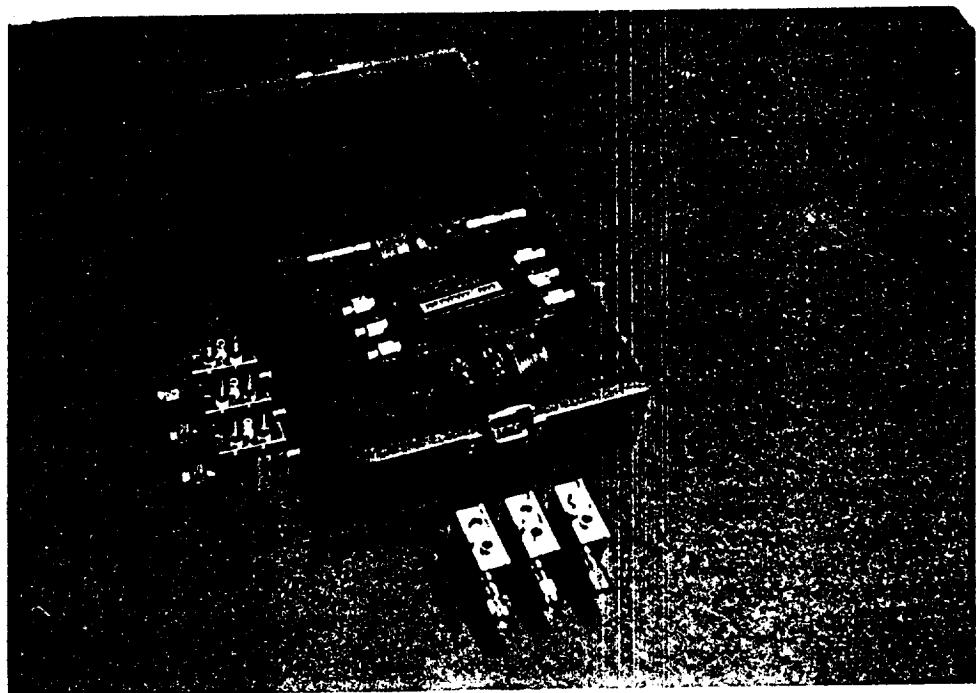


Figure 2.2) Photograph of Sealed Monolithic GaAs Rf Switch Matrix and Buffer Amplifiers Delivered to NASA Lewis Research Center

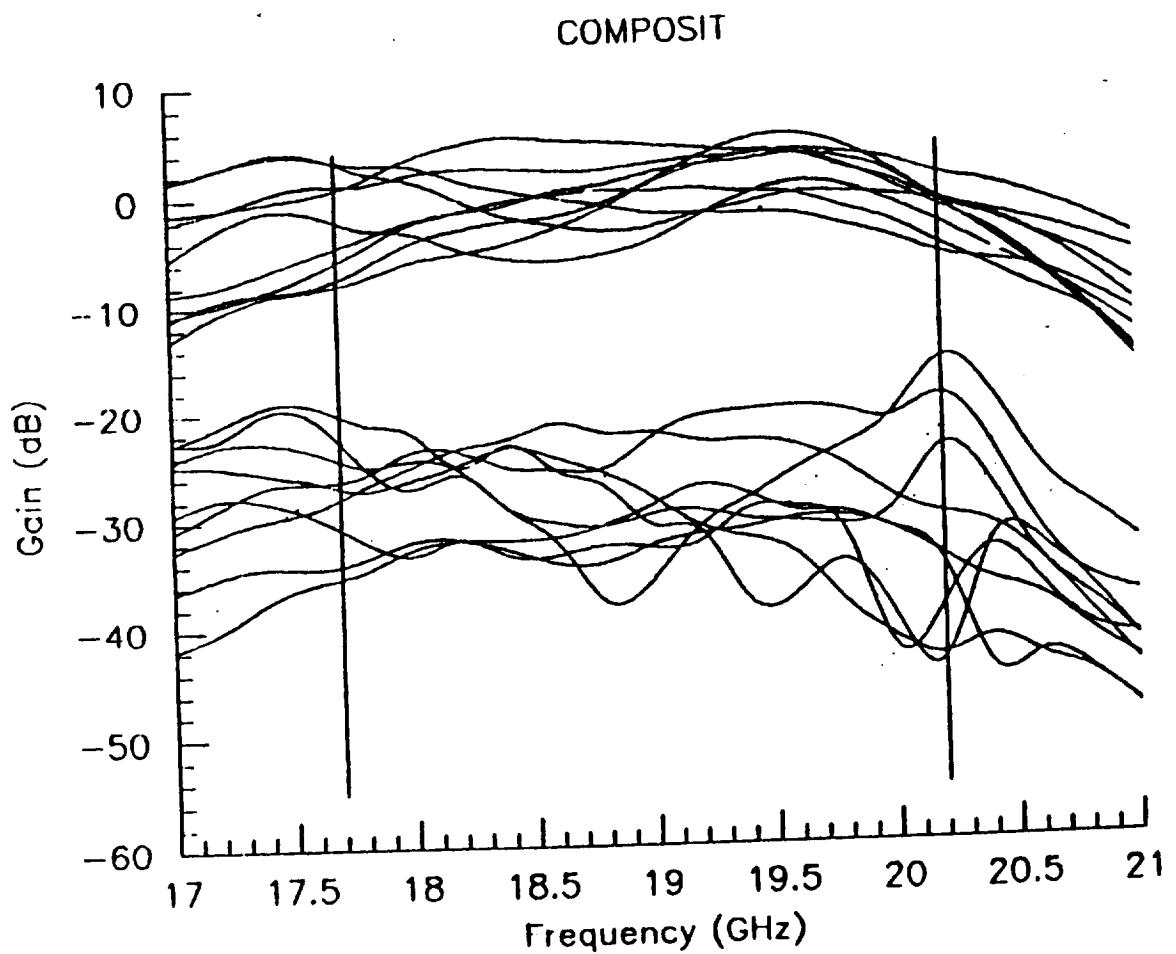


Figure 2.3) Composite Measured Performance of the 3 X 3 Subsystem with Attached Buffer Amplifiers

intersecting crosspoint are plotted in composite form.

In summary, a fully functional 3 X 3 monolithic GaAs 20 GHz RF switch matrix with buffer amplifiers was designed, fabricated, and delivered to NASA, thereby providing proof of concept for MMInc.'s novel fabrication and packaging approach. None the less, more work remains to be done in the areas of chip/package interfacing for high isolation, yield enhancement for higher levels of integration and integration of higher levels of control circuitry. Although MMInc.'s chip and packaging concept is conceptually compatible with high reliability spaceborne applications, further work is also necessary to realize this potential.

3) RF SWITCH MATRIX CIRCUIT DESIGN

A large matrix is composed of monolithic arrays (approximately 10 X 10 crosspoint elements each), which in turn consist of individual crosspoint elements. Each crosspoint contains 8 resonated switching FETs. The importance of high yield is illustrated by the complexity of each 10 X 10 module with almost one thousand FETs and a total gate periphery of 35 cm, as shown in the Table 3.1. Here, the complexity of both the 3 X 3 and 10 X 10 monolithic RF switch are highlighted.

Comparison with the 70 cm total gate periphery of a previously designed 10 X 10 IF switch matrix makes the RF switching approach even more attractive, however it must be recognized that the 100 FETs associated with the buffer amplifiers are higher performance in the present application. None-the-less, the remaining FETs associated with the switch matrix proper and the control logic are essentially the same, indicating the potential for ultimately attaining lower, or at least equivalent, fabrication costs for the RF switch matrix. The added precision required for assembly may, however, offset this apparent advantage.

Under a previous program, a detailed analysis of parasitic coupling effects and losses at 20 GHz was performed and a preliminary baseline design of the necessary switch crosspoint was generated. The crosspoint utilized the same basic FET structure previously developed for an IF switch matrix, however it is operated in a resonant configuration to obtain the necessary isolation at 20 GHz. The basic FET structure is viable at 20 GHz due to its operation as a passive switch, however the buffer amplifiers require high performance FETs with gate lengths of approximately 0.7 microns. Based on this crosspoint, which contains resonating inductive elements to attain isolation, a 3 X 3, 20 GHz switch matrix was designed utilizing a proprietary chip fabrication and packaging technology. Initial performance estimates indicated that RF switch matrix configurations up to 100 X 100 crosspoints may be possible utilizing MMInc.'s new technology.

TABLE 3.1
MONOLITHIC SWITCH MATRIX COMPLEXITY

	<u>3 X 3</u>	<u>10 X 10</u>
8 FETS/CROSSPOINT	72 FETS	800 FETS
2-3 FETS/BUFFER AMP	30 FETS	100 FETS
4 FETS/INVERTER*	36 FETS	400 FETS
TOTAL FET COUNT	138 FETS	940 FETS

* Required if only one control line is used for each crosspoint.

A schematic of the crosspoint and a detailed circuit layout are presented in section 3.2 of this report. After the crosspoints are arranged in a 10 X 10 array a set of forty buffer amplifiers is placed around the periphery as shown in Figure 3-1. Assuming the insertion loss of all crosspoints is the same (although the through and bypass states need not be identical), it is then possible to select the gain of each amplifier such that the insertion loss through the array is 0 dB in all allowed switch states (which will connect all inputs to all outputs in any desired combination). Note that the numbers inside the amplifier symbols in the Figure 3-1 relate to the gains required for that particular buffer, and that circuit losses incurred in interconnecting the arrays can also be compensated by the same amplifiers. With 0 dB insertion loss for both the through and re-routed signals, the arrays can be arranged in arbitrarily large structures while still maintaining 0 dB overall insertion loss. Inherent in this design is the capability of adding redundancy to the final switch matrix as shown in Figure 3-2. A simple feedback loop from one output to an extra input line allows the rerouting of signals around failed crosspoints in the matrix. The rerouting approach could be applied locally to each monolithic matrix or globally to the entire switch matrix (in fact a combination of approaches is possible). Any degree of redundancy is possible by extending the number of modules in the matrix. Control of the redundant lines on the switch matrix can be performed either by a local controller or by command from the master station.

Key to achieving 0 dB insertion loss in each matrix is the accurate control of the gain of all input and output buffer amplifiers. The buffer amplifiers also allow gain slope compensation for the modules provided all crosspoints behave identically. The design requirements and approach for the buffer amplifiers is described in more detail in section 3.4.

A hierarchy of three levels of optimization must be performed to design the switching RF switching portion of a large matrix. At the lowest level the passive FET switching element must be optimized for operation as a switch as opposed to the traditional role of an FET as an

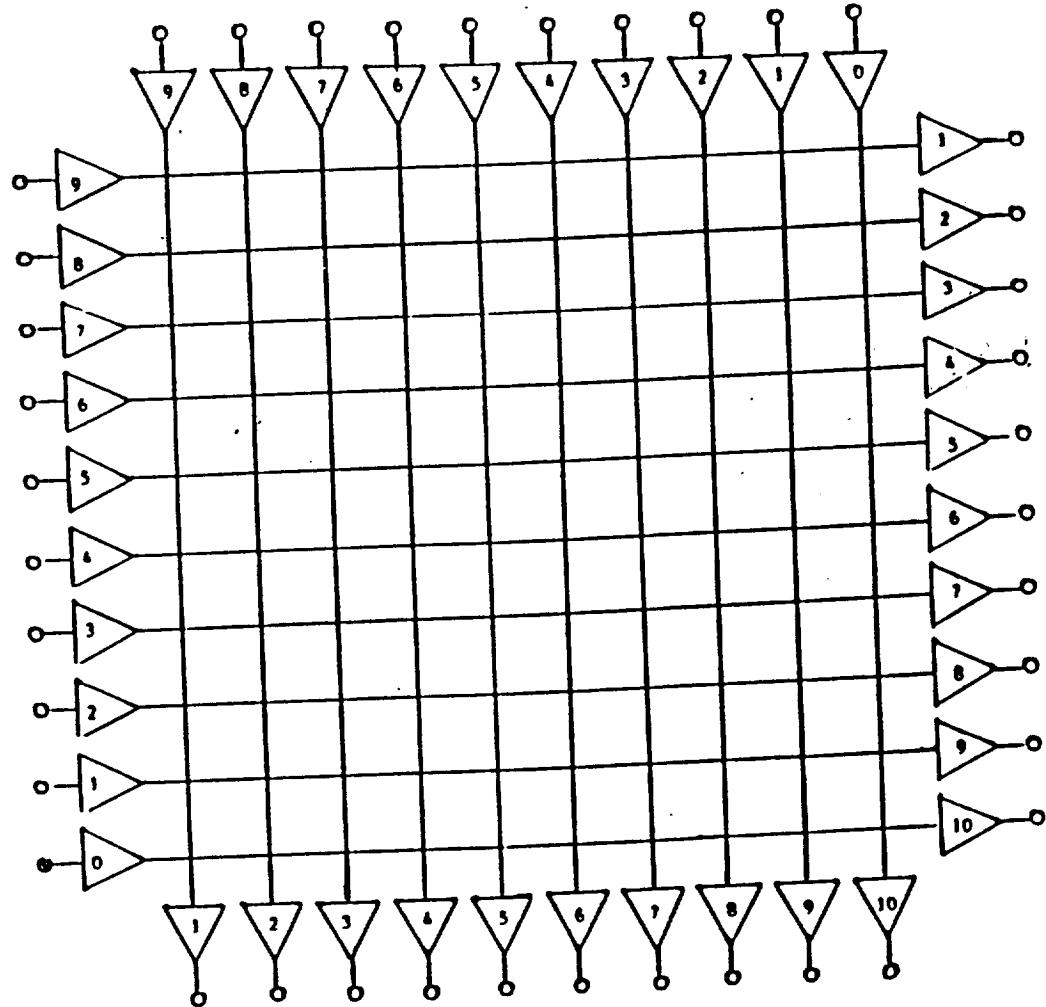


Figure 3.1) Conceptual Layout of the switch matrix with Buffer Amplifiers Placed Around Periphery

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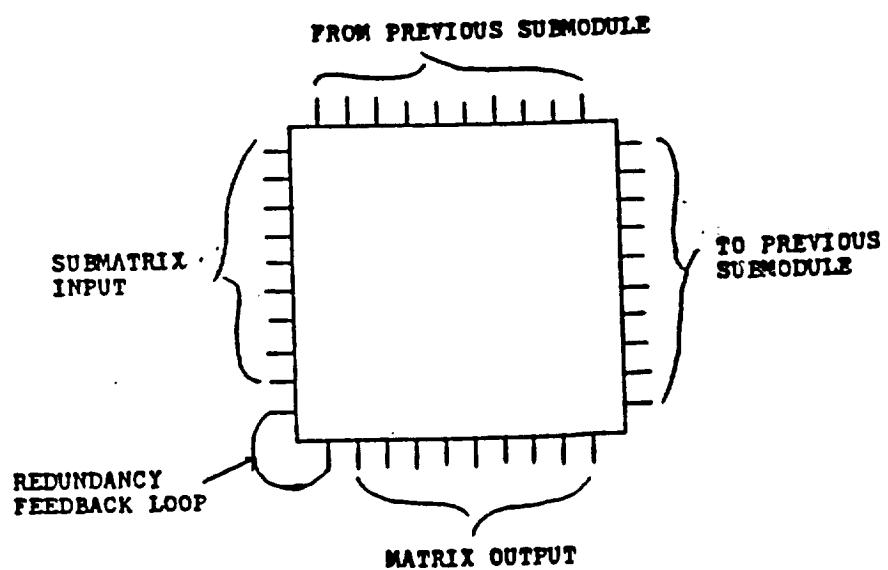


Figure 3.2) External Feedback Connection Demonstrating the Redundancy Capabilities of the RF Switch Matrix Architecture

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active (amplifying) device. FET geometry and doping profiles must be adjusted for low insertion loss in the "on" state, high isolation in the "off" state, adequate dynamic range, and high yield. Following design of the switching element itself, a detailed design of the individual crosspoints must be generated. This design is then iterated to form a monolithic switch matrix. Accurate analysis of the large switching structure (with up to 40 input/output nodes for a 10 X 10 matrix) becomes a significant consideration. Finally, optimization of the packaging structure is required to cascade multiple arrays into a larger (up to 100 X 100 crosspoint) RF switch matrix. These steps were performed under the current program and will be described in the following sections of this report.

3.1) FET Switch

Optimization of the FET switch involves a complex trade-off between crosspoint performance, device yield, and size of the RF switch matrix. The geometry of the passive switching FET utilized in the RF switch matrix is shown in Figure 3.1-1. Most FET physical parameters, such as doping profile, gate length, and the separation between the gate and ohmic contact electrodes, can be the same as for the previously developed IF switch matrix. This is due to the high performance of that device and its use as a passive switch rather than an amplifying device. The gate width must, however, be altered to accommodate the resonator which is necessary for acceptable isolation. A gate width of 200 microns was thus selected for the RF switch matrix, which increases insertion loss but enhances the bandwidth potential, allowing coverage of the full 17.7 to 20.2 GHz band.

The major requirements for a FET operated as a passive switch are that the parasitic resistances associated with the separation between the gate electrode and the two ohmic contacts be minimized, along with the resistance of the ohmic contact resistances themselves. Likewise, the parasitic capacitances between the electrodes must be minimized to keep leakage at a minimum. Low resistances are needed for low loss in the "on" state, while low capacitances are required for high isolation in the "off" state. Inductors will be used to resonate out unavoidable capacitance, however the bandwidth/insertion loss tradeoff improves as the parasitic capacitance is minimized. For high yield, the devices capacitances must be repeatable as well as small.

A major concern for the RF switch matrix is the high component count contained in each monolithic matrix, with the concurrent requirement that individual device yield be extremely high. Toward this end, gate length of the FET must be kept as large as practical, which will also improve "off" isolation. In Program Phase I, it was determined that a gate length of 1.5 microns is a good compromise between high yield and acceptable performance for the RF as well as the RF switch matrix.

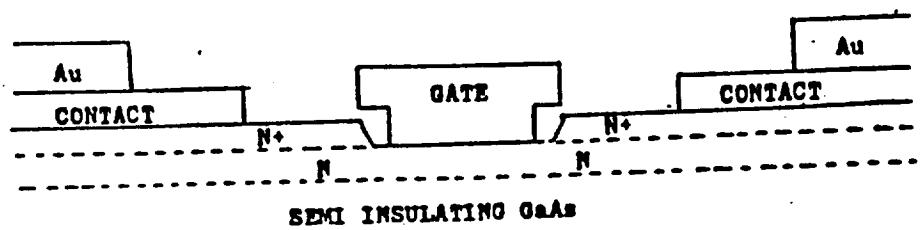
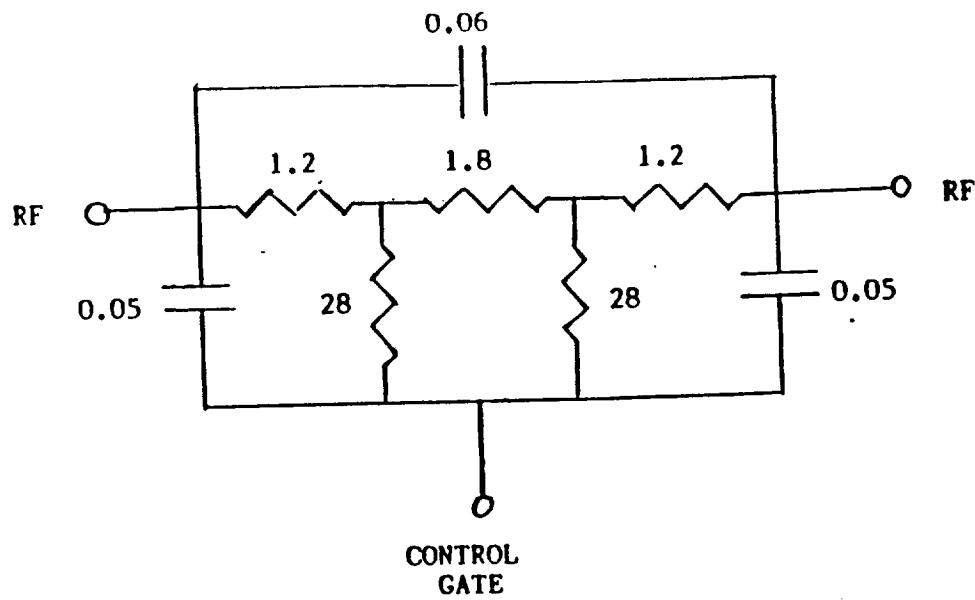


Figure 3.1-1) Geometry of the Passive Switching FET

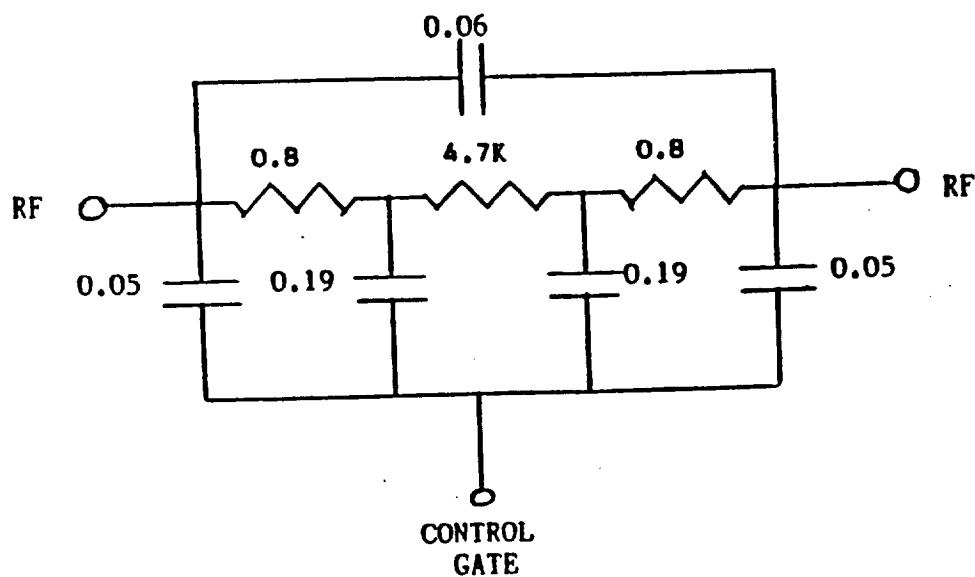
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The optimum doping profile for the FET switch is a trade-off between low "on" resistance, a channel thickness compatible with ion implantation, and a pinch-off voltage large enough to insure that signals passing through the matrix are small compared to the switching levels. With a large pinch off voltage, the FET is not "switched" by the RF signal it should be controlling. Also, the breakdown voltage of the FET switch must be comfortably larger than the combination of the applied control voltage and the instantaneous RF signal level. MMInc. has in-house computer software available capable of accurately simulating and optimizing an ion implantation schedule for the FET switch requirements, including the limited diffusion effects encountered during flash annealing of the doped layer.

In Figure 3.1-2, a model of the switching FET is shown for both the "on" and "off" states. Parasitic resistances associated with the ohmic contacts and the gate to ohmic spacing, included in the model shown, were calculated in a manner analogous to standard FET calculations. Parasitic capacitances are calculated with proprietary in-house software which solves two dimensional Laplace equations for the FET topology, including the effects of various dielectrics such as the GaAs substrate and passivation layers.



a) In the "ON" state.



b) In the "OFF" state.

Figure 3.1-2) Model of the Switching FET

3.2) Single Crosspoint

A schematic of the RF portion of a single crosspoint of the RF switch matrix developed in program phase I is shown in Figure 3.2-1. As shown, input signals from the left side and top are routed to the right side and bottom respectively when the switch is in the "off" or "through" state. In the "on" or "bypass" state, the signal from the left is routed to the bottom while the signal entering from the top is routed to the right output port. Since all elements of the crosspoint are reciprocal, the crosspoint itself is reciprocal and signal paths from output to input also exist. These paths will, however, be interrupted (to the advantage of improved isolation) by the buffer amplifiers around the periphery of the switch matrix.

Each switching element consists of a 200 micron wide by 1.5 micron long switching FET which is shunted by an appropriate inductive transmission line (approximately 100 ohms). The isolation grounds running along the top and bottom of the crosspoint layout are periodically grounded by via holes, enhancing isolation between adjacent signal lines. They also provide a convenient location for routing of the control lines for each crosspoint element. Each path through the matrix transverses two resonated switching FETs. The switches operate in complementary fashion, i.e. when the series switches are "on" for a given path, the switches in the other, undesired, path are "off". Therefore at any instant half of the eight FETs are "on" and the remaining four are "off". For the "through" state, all of the FETs labeled "A" are "on" and all of the "B" FETs are "off". The reverse is true in the "bypass" state. Neither state consumes static DC power, resulting in high efficiency at all times. This is in marked contrast to other types of crosspoint implementations such as diode or actively biased FET arrangements.

Several unique aspects of this design are worthy of further consideration. First, although a system impedance of 50 ohms is maintained throughout the array, the interconnection lines are of much higher impedance. The resulting inductance is used to help "tune out"

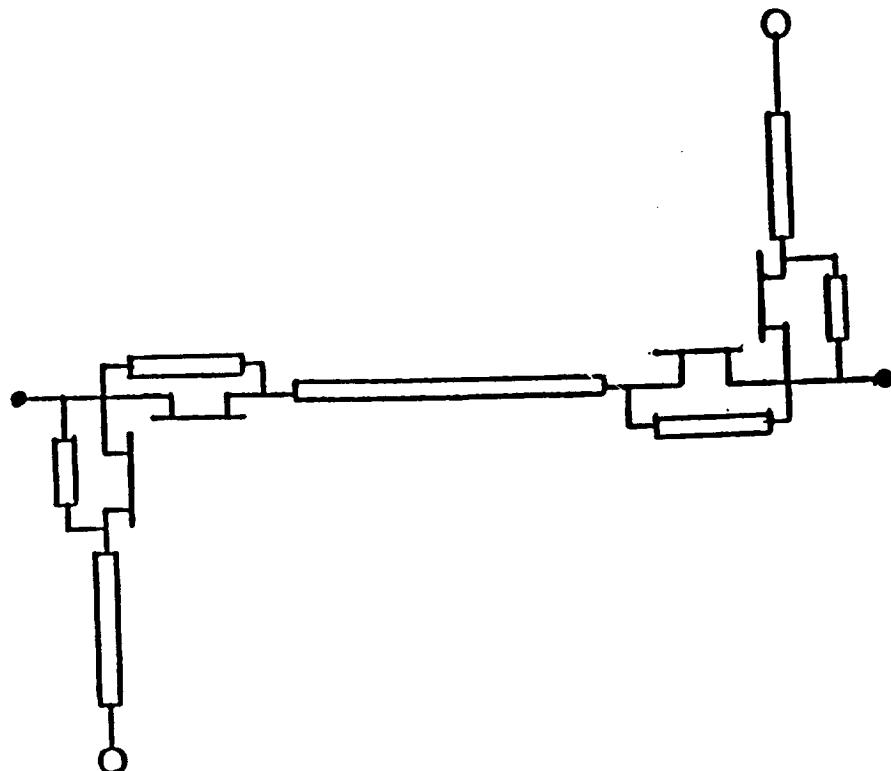


Figure 3.2-1) Schematic of the RF Portion of a Single Crosspoint of
the RF Switch Matrix

the parasitic capacitances of the switching elements, thereby providing improved performance over the frequency band of interest.

Not shown in the schematic are series RF isolation bias resistors at each FET gate terminal, and interconnecting DC lines to minimize the number of bias connections which must be routed to the periphery of the MMIC chip. These control lines run over wide grounding strips between parallel input (and output) lines, thereby providing additional isolation on each side of the two wafer structure.

Final optimization of the crosspoint was done with the aid of "MONO", a proprietary linear circuit analysis and optimization computer program designed specifically for MMIC's. Although standard analysis programs could be used for most of the design, the fact that the crosspoint is a true four port network (as opposed to the two ports more commonly encountered in microwave circuitry) requires an ability to save four port scattering parameters for future processing. These are then used in the analysis of matrix arrays as described in section 6.2.

The predicted performance of this single crosspoint is shown in Figures 3.2-2 and 3.2-3. Figure 3.2-2 shows the predicted insertion loss (port 1 to port 3) and isolation (port 1 to port 4) for the through state, while Figure 3.2-3 shows predicted insertion loss (port 1 to port 4) and isolation (port 1 to port 3) in the bypass state. By symmetry, predicted performance of all remaining signal paths are equivalent to one or the other of these two states. As indicated in the figures, predicted crosspoint insertion loss is approximately 3 dB, and isolation is in excess of 60 dB across the 17.7 to 20.2 GHz band.

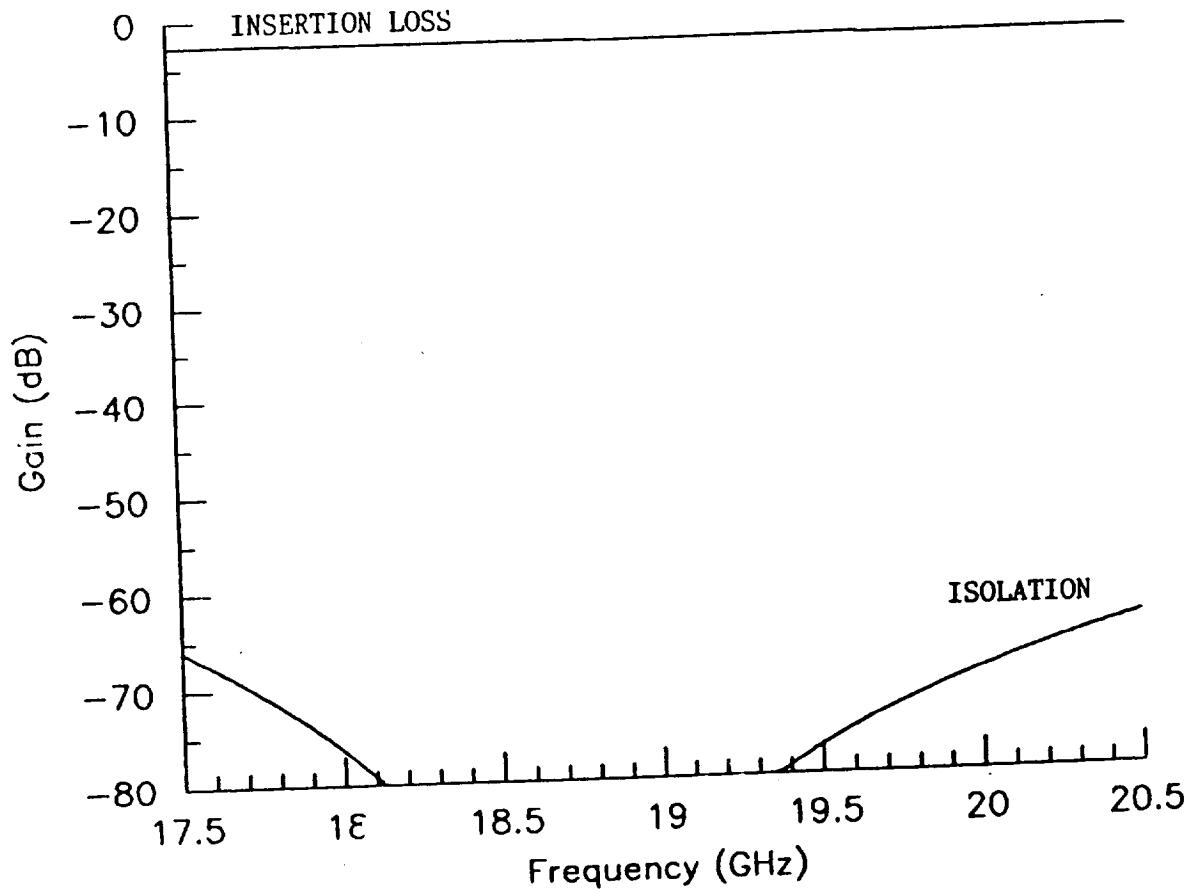


Figure 3.2-2) Predicted Insertion Loss (Port 1 to Port 3) and Isolation (Port 1 to Port 4) for a Single Crosspoint in the Through State.

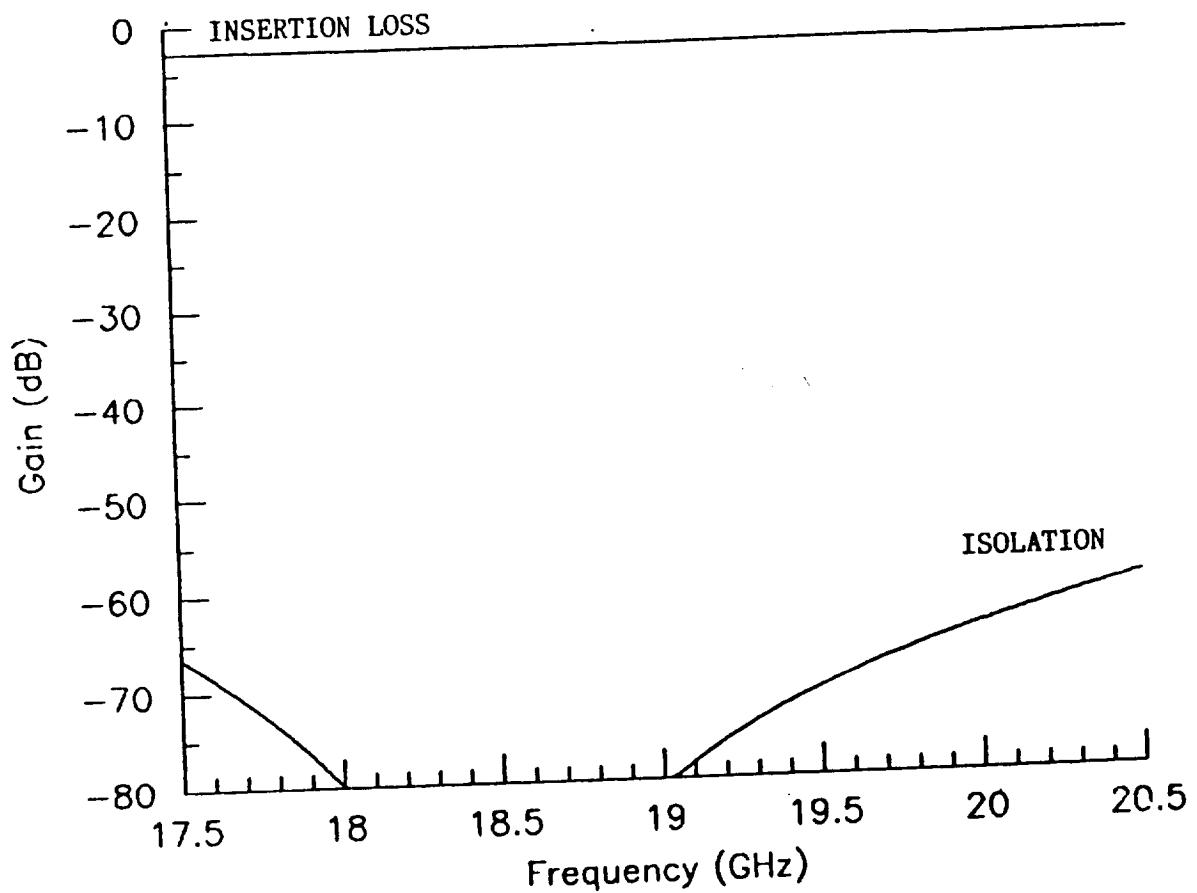


Figure 3.2-3) Predicted Insertion Loss (Port 1 to Port 4) Isolation (Port 1 to Port 3) for a Single Crosspoint in a Bypass State.

3.3) 3 X 3 Monolithic GaAs Switch Matrix

The 3 X 3 monolithic GaAs switch matrix consists of a regular array of the single crosspoints described in section 3.2. Each crosspoint is 1.2 mm square, therefore the active portion of the switch matrix is 3.6 X 3.6 mm. All control lines are routed to the edge of the chip over the ground shielding strips in each crosspoint, therefore no additional internal area is required for these lines. Bonding pads are, however, required on two opposing sides of the chip for the 6 RF and 18 control lines. To maintain the chip symmetry required for packaging and isolation, the MMIC chip must be square. Therefore the total chip size is increased to 4.1 X 4.1 mm. Finally, an additional 0.4 mm ring is placed around the periphery of the chip to accommodate the packaging and assembly, resulting in a chip size of 24.01 square mm. These MMICs are truly VLSI scale parts.

Prior to describing the predicted performance of this 3 X 3 switch matrix, it is necessary to define the matrix port numbering scheme which is utilized throughout this report. This scheme is summarized in Figure 3.3-1. Each side is numbered from top to bottom, while the top input ports and bottom output ports are numbered from left to right. The four sides are then ordered clockwise, starting from the left input ports. When applied to a single ($N=1$) crosspoint, this results in port numbering as previously shown in the schematic in Figure 3.2-1. The row input becomes port 1, the column input port 2, while the row and column outputs become ports 3 and 4, respectively. For a 3 X 3 matrix, the left inputs are ports 1 through 3 and the bottom outputs are ports 10 through 12. In the following discussion, the predicted twelve port scattering parameters are presented for selected switch matrix states. The rows and columns of the matrix are numbered, and at each location the insertion loss in dB (or return loss for the diagonal elements) is shown on top and the insertion phase in degrees is shown on the bottom. At the beginning of each table, a 3 X 3 matrix of 0's and 1's describes the state of the matrix. Each number corresponds to one crosspoint, with a 0 indicating the "through" state and a 1 indicating the "bypass" state.

COLUMN INPUTS

$N+1 \quad N+2 \quad N+3 \dots 2N$

1				2N+1	R
				O	O
2				2N+2	W
	N	X	N		
3				2N+3	O
.				.	U
.				.	T
.				.	P
.				.	U
.				.	T
.				.	T
N				3N	S

SWITCH MATRIX

$3N+1 \quad 3N+2 \quad 3N+3 \dots \dots \quad 4N$

COLUMN OUTPUTS

Figure 3.3-1) Port Numbering Scheme for the RF Switch Matrix.

With this background, the predicted performance for the full 3 X 3 matrix can be described. There are a large number of possible states for the 3 X 3 RF switch matrix ($2^9 = 512$), therefore predicted performance was not calculated for all states. Three states of particular interest were, however, predicted. The resulting 12 port scattering parameters of these states at 17.5, 19 and 20.5 GHz are shown in Tables 3.3-1 through 3.3-4. In Table 3.3-1, the through state is presented. In this instance, all left input signals are routed to the right and all top input signals are routed to the bottom. None of the through substrate via holes are utilized.

In Table 3.3-2, one of the many fully bypassed states is presented. Here, the left hand inputs are all routed to the bottom three output ports, with port 1 routed to port 10, port 2 to port 11, and port 3 to port 12. All of the through substrate via holes are utilized in this case. Due to symmetry, ports 4 through 6 are similarly routed to ports 7 through 9. Note that in this case, as in the through state, all path lengths are the same. Therefore insertion loss through the matrix (without the compensating buffer amplifiers) is nearly identical for all transmission paths.

Finally, in Table 3.3-3 another fully bypassed state is presented. In this case port 1 is routed to port 12, port 2 to port 11, and port 3 to port 10. Note that in this instance both the shortest possible path length (one crosspoint) and the longest possible path length (5 crosspoints) are encountered. Therefore insertion loss varies considerably prior to addition of the buffer amplifiers. Table 3.3-4 shows the effect of adding the buffer amplifiers. Note that insertion loss is nearly 0 dB in all transmission states, and that isolation is significantly enhanced in some of the reverse coupled states due to the high isolation of the buffers.

TABLE 3.3-1)

PREDICTED PERFORMANCE OF THE 3 X 3 MONOLITHIC GaAs RF SWITCH
MATRIX IN THE THROUGH STATE WITHOUT BUFFER AMPLIFIERS

000
000
000

F = 17.50

	1	2	3	4	5	6	7	8	9	10	11	12
1)	16 -112	130 44	132 -45	61 2	64 -89	66 -178	9 85	131 -65	134 -174	73 -133	76 145	78 36
2)	130 44	16 -112	130 62	64 -89	67 177	70 89	118 -176	9 85	131 -66	71 -24	73 -106	76 143
3)	132 -45	130 62	16 -112	66 -178	70 89	72 0	120 95	118 -175	9 85	67 57	71 -24	73 -133
4)	61 2	64 -89	66 -178	16 -112	130 44	132 -45	73 -133	76 145	78 36	9 85	131 -65	134 -174
5)	64 -89	67 177	70 89	130 44	16 -112	130 62	71 -24	73 -106	76 143	118 -176	9 85	131 -66
6)	66 -178	70 89	72 0	132 -45	130 62	16 -112	67 57	71 -24	73 -133	120 95	118 -175	9 85
7)	9 85	118 -176	120 95	73 -133	71 -24	67 57	17 -111	130 64	132 -44	72 0	70 90	66 -178
8)	131 -65	9 85	118 -175	76 145	73 -106	71 -24	130 64	17 -111	130 45	70 90	67 178	64 -89
9)	134 -174	131 -66	9 85	78 36	76 143	73 -133	132 -44	130 45	17 -111	66 -178	64 -89	61 3
10)	73 -133	71 -24	67 57	9 85	118 -176	120 95	72 0	70 90	66 -178	17 -111	130 64	132 -44
11)	76 145	73 -106	71 -24	131 -65	9 85	118 -175	70 90	67 178	64 -89	130 64	17 -111	130 45
12)	78 36	76 143	73 -133	134 -174	131 -66	9 85	66 -178	64 -89	61 3	132 -44	130 45	17 -111

TABLE 3.3-1) CONTINUED

000
000
000

F = 19.00

	1	2	3	4	5	6	7	8	9	10	11	12
1)	16	159	162	73	76	79	9	157	162	88	90	94
	-111	-52	-153	-62	-166	92	49	-165	73	166	70	-53
2)	159	16	157	76	80	82	143	9	157	83	85	90
	-52	-111	-28	-166	88	-10	31	49	-166	-73	-173	69
3)	162	157	16	79	82	85	145	143	9	81	83	88
	-153	-28	-111	92	-10	-111	-68	31	49	25	-72	165
4)	73	76	79	16	159	162	88	90	94	9	157	162
	-62	-166	92	-111	-52	-153	166	70	-53	49	-165	73
5)	76	80	82	159	16	157	83	85	90	143	9	157
	-166	88	-10	-52	-111	-28	-73	-173	69	31	49	-166
6)	79	82	85	162	157	16	81	83	88	145	143	9
	92	-10	-111	-153	-28	-111	25	-72	165	-68	31	49
7)	9	143	145	88	83	81	17	157	162	85	82	79
	49	31	-68	166	-73	25	-110	-27	-153	-110	-9	93
8)	157	9	143	90	85	83	157	17	159	82	80	76
	-165	49	31	70	-173	-72	-27	-110	-52	-9	90	-165
9)	162	157	9	94	90	88	162	159	17	79	76	73
	73	-166	49	-53	69	165	-153	-52	-110	93	-165	-61
10)	88	83	81	9	143	145	85	82	79	17	157	162
	166	-73	25	49	31	-68	-110	-9	93	-110	-27	-153
11)	90	85	83	157	9	143	82	80	76	157	17	159
	70	-173	-72	-165	49	31	-9	90	-165	-27	-110	-52
12)	94	90	88	162	157	9	79	76	73	162	159	17
	-53	69	165	73	-166	49	93	-165	-61	-153	-52	-110

TABLE 3.3-1) CONTINUED

000
000
000

F = 20.50

	1	2	3	4	5	6	7	8	9	10	11	12
1)	16 -96	114 24	117 -86	51 -55	55 -172	58 76	10 11	113 -120	119 116	66 -173	66 66	74 -61
2)	114 24	16 -96	111 32	55 -172	59 70	62 -40	101 23	10 11	113 -120	60 -51	62 -171	68 66
3)	117 -86	111 32	16 -96	58 76	62 -40	65 -152	104 -88	101 23	10 11	57 68	60 -52	66 -174
4)	51 -55	55 -172	58 76	16 -96	114 24	117 -86	66 -173	68 66	74 -61	10 11	113 -120	119 116
5)	55 -172	59 70	62 -40	114 24	16 -96	111 32	60 -51	62 -171	68 66	101 23	10 11	113 -120
6)	58 76	62 -40	65 -152	117 -86	111 32	16 -96	57 68	60 -52	66 -174	104 -88	101 23	10 11
7)	10 11	101 23	104 -88	66 -173	60 -51	57 68	17 -93	111 32	117 -86	65 -152	62 -39	58 77
8)	113 -120	10 11	101 23	68 66	62 -171	60 -52	111 32	17 -93	114 24	62 -39	59 72	55 -170
9)	119 116	113 -120	10 11	74 -61	68 66	66 -174	117 -86	114 24	17 -93	58 77	55 -170	51 -53
10)	66 -173	60 -51	57 68	10 11	101 23	104 -88	65 -152	62 -39	58 77	17 -93	111 32	117 -86
11)	68 66	62 -171	60 -52	113 -120	10 11	101 23	62 -39	59 72	55 -170	111 32	17 -93	114 24
12)	74 -61	68 66	66 -174	119 116	113 -120	10 11	58 77	55 -170	51 -53	117 -86	114 24	17 -93

TABLE 3.3-2)

PREDICTED PERFORMANCE OF THE 3 X 3 MONOLITHIC GaAs RF SWITCH MATRIX
IN ONE POSSIBLE BYPASS STATE WITHOUT BUFFER AMPLIFIERS

100
010
001

F = 17.50

	1	2	3	4	5	6	7	8	9	10	11	12
1)	17 -83	63 -90	66 -177	61 1	132 56	128 -35	73 -127	134 -57	136 -176	9 86	76 144	78 37
2)	63 -90	15 -124	69 87	132 56	67 175	138 -84	121 -179	73 -104	134 -58	73 -32	9 84	76 143
3)	66 -177	69 87	16 -105	128 -35	138 -84	72 0	124 95	121 -178	72 -128	67 60	73 -31	9 86
4)	61 1	132 56	128 -35	17 -83	63 -90	66 -177	9 86	76 144	78 37	73 -127	134 -57	136 -176
5)	132 56	67 175	138 -84	63 -90	15 -124	69 87	73 -32	9 84	76 143	121 -179	73 -104	134 -58
6)	128 -35	138 -84	72 0	66 -177	69 87	16 -105	67 60	73 -31	9 86	124 95	121 -178	72 -128
7)	73 -127	121 -179	124 95	9 86	73 -32	67 60	17 -104	69 88	66 -177	72 0	138 -84	128 -35
8)	134 -57	73 -104	121 -178	76 144	9 84	73 -31	69 88	16 -124	63 -89	138 -84	67 175	132 56
9)	136 -176	134 -58	72 -128	78 37	76 143	9 86	66 -177	63 -89	17 -80	128 -35	132 56	61 2
10)	9 86	73 -32	67 60	73 -127	121 -179	124 95	72 0	138 -84	128 -35	17 -104	69 88	66 -177
11)	76 144	9 84	73 -31	134 -57	73 -104	121 -178	138 -84	67 175	132 56	69 88	16 -124	63 -89
12)	78 37	76 143	9 86	136 -176	134 -58	72 -128	128 -35	132 56	61 2	66 -177	63 -89	17 -80

TABLE 3.3-2) CONTINUED

100
010
001

F = 19.00

	1	2	3	4	5	6	7	8	9	10	11	12
1)	16 -81	76 -167	79 93	84 -88	169 -55	167 177	98 143	171 173	176 40	9 50	89 69	93 -52
2)	76 -167	17 -126	82 -12	169 -55	91 61	171 116	158 3	95 159	171 171	85 -64	9 48	90 68
3)	79 93	82 -12	16 -106	167 177	171 116	97 -138	160 -93	158 3	98 143	80 20	85 -64	9 50
4)	84 -88	169 -55	167 177	16 -81	76 -167	79 93	9 50	89 69	93 -52	98 143	171 173	176 40
5)	169 -55	91 61	171 116	76 -167	17 -126	82 -12	85 -64	9 48	90 68	158 3	95 159	171 171
6)	167 177	171 116	97 -138	79 93	82 -12	16 -106	80 20	85 -64	9 50	160 -93	158 3	98 143
7)	98 143	158 3	160 -93	9 50	85 -64	80 20	16 -105	82 -11	79 94	97 -137	171 117	167 177
8)	171 173	95 159	158 3	89 69	9 48	85 -64	82 -11	17 -126	76 -166	171 117	91 62	168 -55
9)	176 40	171 171	98 143	93 -52	90 68	9 50	79 94	76 -166	16 -77	167 177	168 -55	84 -87
10)	9 50	85 -64	80 20	98 143	158 3	160 -93	97 -137	171 117	167 177	16 -105	82 -11	79 94
11)	89 69	9 48	85 -64	171 173	95 159	158 3	171 117	91 62	168 -55	82 -11	17 -126	76 -166
12)	93 -52	90 68	9 50	176 40	171 171	98 143	167 177	168 -55	84 -87	79 94	76 -166	16 -77

TABLE 3.3-2) CONTINUED

100
010
001

F = 20.50

	1	2	3	4	5	6	7	8	9	10	11	12
1)	14 -71	55 -172	58 76	57 -57	117 20	119 -123	70 -179	120 -123	128 107	10 11	68 65	74 -61
2)	55 -172	18 -102	62 -41	117 20	65 67	121 147	110 18	67 -177	121 -124	60 -40	10 10	68 65
3)	58 76	62 -41	15 -99	119 -123	121 147	71 -155	113 -89	110 18	70 179	58 63	60 -41	10 11
4)	57 -57	117 20	119 -123	14 -71	55 -172	58 76	10 11	68 65	74 -61	70 -179	120 -123	128 107
5)	117 20	65 67	121 147	55 -172	18 -102	62 -41	60 -40	10 10	68 65	110 18	67 -177	121 -124
6)	119 -123	121 147	71 -155	58 76	62 -41	15 -99	58 63	60 -41	10 11	113 -89	110 18	70 179
7)	70 -179	110 18	113 -89	10 11	60 -40	58 63	16 -97	62 -40	58 77	71 -155	121 148	119 -123
8)	120 -123	67 -177	110 18	68 65	10 10	60 -41	62 -40	19 -100	55 -171	121 148	65 68	117 20
9)	128 107	121 -124	70 179	74 -61	68 65	10 11	58 77	55 -171	15 -68	119 -123	117 20	57 -56
10)	10 11	60 -40	58 63	70 -179	110 18	113 -89	71 -155	121 148	119 -123	16 -97	62 -40	58 77
11)	68 65	10 10	60 -41	120 -123	67 -177	110 18	121 148	65 68	117 20	62 -40	19 -100	55 -171
12)	74 -61	68 65	10 11	128 107	121 -124	70 179	119 -123	117 20	57 -56	58 77	55 -171	15 -68

TABLE 3.3-3)

PREDICTED PERFORMANCE OF THE 3 X 3 MONOLITHIC
GaAs RF SWITCH MATRIX IN A SECOND POSSIBLE BYPASS STATE
WITHOUT BUFFER AMPLIFIERS

001
010
100

F = 17.50

	1	2	3	4	5	6	7	8	9	10	11	12
1)	17 -104	128 64	128 -34	60 2	61 -91	66 -179	72 -128	71 142	73 48	134 -39	124 -21	15 -96
2)	128 64	15 -124	137 85	61 -91	67 175	178 -84	184 -22	73 -104	71 141	125 166	9 84	124 -22
3)	128 -34	137 85	14 -91	66 -179	178 -84	187 -156	187 -119	183 -23	72 -128	3 -91	125 166	134 -39
4)	60 2	61 -91	66 -179	17 -104	128 64	128 -34	134 -39	124 -21	15 -96	72 -128	71 142	73 48
5)	61 -91	67 175	178 -84	128 64	15 -124	137 85	125 166	9 84	124 -22	184 -22	73 -104	71 141
6)	66 -179	178 -84	187 -156	128 -34	137 85	14 -91	3 -91	125 166	134 -39	187 -119	183 -23	72 -128
7)	72 -128	184 -22	187 -119	134 -39	125 166	3 -91	15 -88	137 87	128 -34	187 -155	178 -83	66 -178
8)	71 142	73 -104	183 -23	124 -21	9 84	125 166	137 87	16 -124	128 64	178 -83	67 175	61 -90
9)	73 48	71 141	72 -128	15 -96	124 -22	134 -39	128 -34	128 64	18 -103	66 -178	61 -90	60 3
10)	134 -39	125 166	3 -91	72 -128	184 -22	187 -119	187 -155	178 -83	66 -178	15 -88	137 -87	128 -34
11)	124 -21	9 84	125 166	71 142	73 -104	183 -23	178 -83	67 175	61 -90	137 87	16 -124	128 64
12)	15 -96	124 -22	134 -39	73 48	71 141	72 -128	66 -178	61 -90	60 3	128 -34	128 64	18 -103

TABLE 3.3-3) CONTINUED

001
010
100

F = 19.00

	1	2	3	4	5	6	7	8	9	10	11	12
1)	16	153	166	73	74	90	98	85	87	180	151	16
	-101	-49	174	-65	-175	66	143	75	-40	19	179	-156
2)	153	17	168	74	91	229	241	95	85	161	9	151
	-49	-126	-22	-175	61	34	117	159	74	10	48	178
3)	166	168	13	90	229	249	248	241	98	3	161	180
	174	-22	-92	66	34	-71	0	116	142	-103	10	21
4)	73	74	90	16	153	166	180	151	16	98	85	87
	-65	-175	66	-101	-49	174	19	179	-156	143	75	-40
5)	74	91	229	153	17	168	161	9	151	241	95	85
	-175	61	34	-49	-126	-22	10	48	178	117	159	74
6)	90	229	249	166	168	13	3	161	180	248	241	98
	66	34	-71	174	-22	-92	-103	10	21	0	116	142
7)	98	241	248	180	161	3	14	168	166	249	229	90
	143	117	0	19	10	-103	-89	-22	174	-70	35	67
8)	85	95	241	151	9	161	168	17	153	229	91	74
	75	159	116	179	48	10	-22	-126	-49	35	62	-174
9)	87	85	98	16	151	180	166	153	16	90	74	73
	-40	74	142	-156	178	21	174	-49	-100	67	-174	-64
10)	180	161	3	98	241	248	249	229	90	14	168	166
	19	10	-103	143	117	0	-70	35	67	-89	-22	174
11)	151	9	161	85	95	241	229	91	74	168	17	153
	179	48	10	75	159	116	35	62	-174	-22	-126	-49
12)	16	151	180	87	85	98	90	74	73	166	153	16
	-156	178	21	-40	74	142	67	-174	-64	174	-49	-100

TABLE 3.3-3) CONTINUED

001

010

100

F = 20.50

	1	2	3	4	5	6	7	8	9	10	11	12
1)	15 -95	110 -6	120 -131	52 -52	55 176	64 73	70 179	62 76	66 -52	120 12	112 -173	17 138
2)	110 -6	18 -102	115 38	55 176	65 67	160 72	167 -155	67 -177	62 76	115 55	10 10	112 -175
3)	120 -131	115 38	12 -90	64 73	160 72	175 -37	173 77	167 -155	70 179	3 -115	115 55	120 12
4)	52 -52	55 176	64 73	15 -95	110 -6	120 -131	120 12	112 -173	17 138	70 179	62 76	66 -52
5)	55 176	65 67	160 72	110 -6	18 -102	115 38	115 55	10 10	112 -175	167 -155	67 -177	62 76
6)	64 73	160 72	175 -37	120 -131	115 38	12 -90	3 -115	115 55	120 12	173 77	167 -155	70 179
7)	70 179	167 -155	173 77	120 12	115 55	3 -115	13 -86	115 38	120 -131	175 -37	160 73	64 74
8)	62 76	67 -177	167 -155	112 -173	10 10	115 55	115 38	19 -100	110 -5	160 73	65 68	55 178
9)	66 -52	62 76	70 179	17 138	112 -175	120 12	120 -131	110 -5	15 -93	64 74	55 178	52 -51
10)	120 12	115 55	3 -115	70 179	167 -155	173 77	175 -37	160 73	64 74	13 -86	115 38	120 -131
11)	112 -173	10 10	115 55	62 76	67 -177	167 -155	160 73	65 68	55 178	115 38	19 -100	110 -5
12)	17 138	112 -175	120 12	66 -52	62 76	70 179	64 74	55 178	52 -51	120 -131	110 -5	15 -93

TABLE 3.3-4)

PREDICTED PERFORMANCE OF THE 3 X 3 MONOLITHIC GaAs RF
SWITCH MATRIX IN THE SAME BYPASS STATE AS FOR TABLE 3.3-3,
INCLUDING THE EFFECTS OF THE BUFFER AMPLIFIERS

001
010
100

F = 17.50

	1	2	3	4	5	6	7	8	9	10	11	12
1)	21	135	138	64	68	76	87	91	98	149	144	40
	-173	12	-69	-67	-143	-214	-180	72	-38	-91	-91	-83
2)	127	17	142	60	69	183	194	88	91	135	24	144
	12	-159	68	-143	140	-101	-57	-156	71	132	32	-91
3)	122	134	14	60	175	187	192	193	87	8	135	149
	-69	68	-90	-214	-101	-155	-136	-57	-180	-108	132	-91
4)	64	68	76	21	135	138	149	144	40	87	91	98
	-67	-143	-214	-173	12	-69	-91	-91	-183	-180	72	-38
5)	60	69	183	127	17	142	135	24	144	194	88	91
	-143	140	-101	12	-159	68	132	32	-91	-57	-156	71
6)	60	175	187	122	134	14	8	135	149	192	193	87
	-214	-101	-155	-69	68	-90	-108	132	-91	-136	-57	-180
7)	63	178	184	125	119	0	17	144	140	189	185	78
	-180	-57	-136	-91	132	-108	-123	35	-103	-189	-135	-248
8)	59	64	177	112	0	119	136	20	137	177	71	70
	72	-156	-57	-91	32	132	35	-194	-22	-135	106	-177
9)	58	59	63	0	112	125	124	129	24	62	62	66
	-38	71	-180	-183	-91	-91	-103	-22	-207	-248	-177	-101
10)	125	119	0	63	178	184	189	185	78	17	144	140
	-91	132	-108	-180	-57	-136	-189	-135	-248	-123	35	-103
11)	112	0	119	59	64	177	177	71	70	136	20	137
	-91	32	132	72	-156	-57	-135	106	-177	35	-194	-22
12)	0	112	125	58	59	63	62	62	66	124	129	24
	-183	-91	-91	-38	71	-180	-248	-177	-101	-103	-22	-207

TABLE 3.3-4) CONTINUED

001
010
100

F = 19.00

	1	2	3	4	5	6	7	8	9	10	11	12
1)	20	160	176	77	81	100	113	105	112	195	171	41
	-177	-105	136	-140	-232	29	87	0	-134	-36	103	-251
2)	152	19	173	73	93	234	251	110	105	171	24	171
	-105	-164	-41	-232	23	16	80	103	0	-26	-7	102
3)	160	165	13	84	226	249	253	251	113	8	171	195
	136	-41	-91	29	16	-70	-19	78	86	-121	-26	-35
4)	77	81	100	20	160	176	195	171	41	113	105	112
	-140	-232	29	-177	-105	136	-36	103	-251	87	0	-134
5)	73	93	234	152	19	173	171	24	171	251	110	105
	-232	23	16	-105	-164	-41	-26	-7	102	80	103	0
6)	84	226	249	160	165	13	8	171	195	253	251	113
	29	16	-70	136	-41	-91	-121	-26	-35	-19	78	86
7)	89	235	245	171	155	0	16	175	178	251	236	102
	87	80	-19	-36	-26	-121	-127	-78	98	-108	-20	-8
8)	73	86	235	139	0	155	167	21	162	228	95	83
	0	103	78	103	-7	-26	-78	-202	-143	-20	-13	-269
9)	72	73	89	1	139	171	162	154	22	86	75	79
	-134	0	86	-251	102	-35	98	-143	-213	-8	-269	-177
10)	171	155	0	89	235	245	251	236	102	16	175	178
	-36	-26	-121	87	80	-19	-108	-20	-8	-127	-78	98
11)	139	0	155	73	86	235	228	95	83	167	21	162
	103	-7	-26	0	103	78	-20	-13	-269	-78	-202	-143
12)	1	139	171	72	73	89	86	75	79	162	154	22
	-251	102	-35	-134	0	86	-8	-269	-177	98	-143	-213

TABLE 3.3-4) CONTINUED

001
010
100

F = 20.50

	1	2	3	4	5	6	7	8	9	10	11	12
1)	19 -176	117 -67	130 -172	56 -133	62 115	74 32	85 118	82 -4	91 -154	135 -48	132 -255	42 36
2)	109 -67	20 -143	120 18	54 115	67 26	165 52	177 -196	82 -238	82 -4	125 15	25 -50	132 -256
3)	114 -172	112 18	12 -89	58 32	157 52	175 -37	178 57	177 -195	85 118	8 -135	125 14	135 -48
4)	56 -133	62 115	74 32	19 -176	117 -67	130 -172	135 -48	132 -255	42 36	85 118	82 -4	91 -154
5)	54 115	67 26	165 52	109 -67	20 -143	120 18	125 15	25 -50	132 -256	177 -196	82 -238	82 -4
6)	58 32	157 52	175 -37	114 -172	112 18	12 -89	8 -135	125 14	135 -48	178 57	177 -195	85 118
7)	61 118	161 -196	170 57	111 -48	109 15	0 -135	15 -127	122 -22	132 -213	177 -77	167 12	76 -7
8)	50 -4	58 -238	161 -195	100 -255	1 -50	109 14	114 -22	23 -182	119 -107	159 12	69 -13	64 76
9)	51 -154	50 -4	61 118	2 36	100 -256	111 -48	116 -213	111 -107	21 -216	60 -7	56 76	58 -173
10)	111 -48	109 15	0 -135	61 118	161 -196	170 57	177 -77	167 12	76 -7	15 -127	122 -22	132 -213
11)	100 -255	1 -50	109 14	50 -4	58 -238	161 -195	159 12	69 -13	64 76	114 -22	23 -182	119 -107
12)	2 36	100 -256	111 -48	51 -154	50 -4	61 118	60 -7	56 76	58 -173	116 -213	111 -107	21 -216

3.4) Buffer Amplifier Design

The buffer amplifier was not considered in detail in Phase I of the current program since the major objective at that time was to examine the feasibility of the RF switch matrix approach. The feasibility of designing and fabricating a monolithic buffer amplifier covering the 17.7 to 20.2 GHz band was never in question, since several GaAs monolithic amplifiers of comparable performance have been previously described in the literature. However, the buffer amplifier is a key element of the RF switch matrix and had to be considered in detail during phase II in order to obtain an overall insertion loss of 0 dB.

The buffer amplifiers are arranged around the matrix as previously shown in Figure 3.1, with gains as indicated in the figure. The units of gain are "crosspoints", where one "crosspoint" is equal to the insertion loss of a single crosspoint circuit (approximately 3 dB). It is assumed that the crosspoints are all identical. When the gains specified are achieved, the insertion loss of any valid path through the matrix is exactly 0 dB, allowing the cascading of the modules to any desired level consistent with acceptable packaging yield (up to 100 X 100 or more crosspoints). Besides having the prescribed gain, the amplifiers must satisfy several additional criteria. In particular, high isolation from output to input is desirable in order to minimize cross talk between modules and to reduce ringing effects due to separations in the package and interconnecting bond wires.

For a 10 X 10 array, there are a total of 40 buffer amplifiers around the periphery of the chip, with gains varying from 0 dB (no amplifier) for segments of those paths which pass through few crosspoints (a minimum of one) to as much as 30 dB for longer paths (as many as 19 crosspoints). The amplifiers must be physically narrow enough to fit between the line to line spacings of the matrix (easily accomplished), and although the length is not crucial they should be as short as possible to conserve valuable GaAs real estate. Since there are so many amplifiers on each chip, high yield devices must be utilized to insure that matrix yield is not severely limited by the amplifiers.

At the frequencies under consideration for the RF switch matrix 0.7 micron FETs have ample gain and have been selected for this application. Although it is possible to fabricate a separate chip for each of the four rows of buffer amplifiers to increase yields, the packaging and interconnection problem becomes more severe and should be avoided, if possible. Thus for the current program, the designs incorporated separate chips to simplify evaluation of the components in the cross point switch matrix.

Due to the large variation in gain required for the 3 X 3 RF switch matrix, two buffer amplifiers were designed. The schematic of the first, a single stage amplifier, is shown in Figure 3.4-1. Predicted performance is shown in Figure 3.4-2.

A composite pen plot of the digitized single stage buffer amplifier is shown in Figure 3.4-3. The chip size is 2.5 by 1.1 millimeters, allowing for direct cascading with the 3 X 3 RF switch matrix. Note that the three control lines from the RF switch matrix that terminate at this buffer amplifier are continued the length of the amplifier, therefore all bond pads of a monolithic switch matrix with integral buffer amplifiers remain on the periphery of the chip. Drain and source bias are also routed the complete length of the amplifier for cascading if necessary. The extension in chip length is included for compatibility with the two stage buffer amplifier described next.

For the higher gain buffer amplifiers, a two stage design was also generated. The schematic of this amplifier is shown in Figure 3.4-4, and the predicted performance is shown in Figure 3.4-5. Once again, the gain is adjustable with gate bias. In fact, this amplifier is designed to compensate for both two and three crosspoints depending on applied gate bias. The composite pen plot of the digitized amplifier is shown in Figure 3.4-6. Note that the chip size is identical to the one stage buffer, and that all input, output, and bias lines are in the same location for each chip. This allows maximum flexibility in final RF switch matrix configuration.

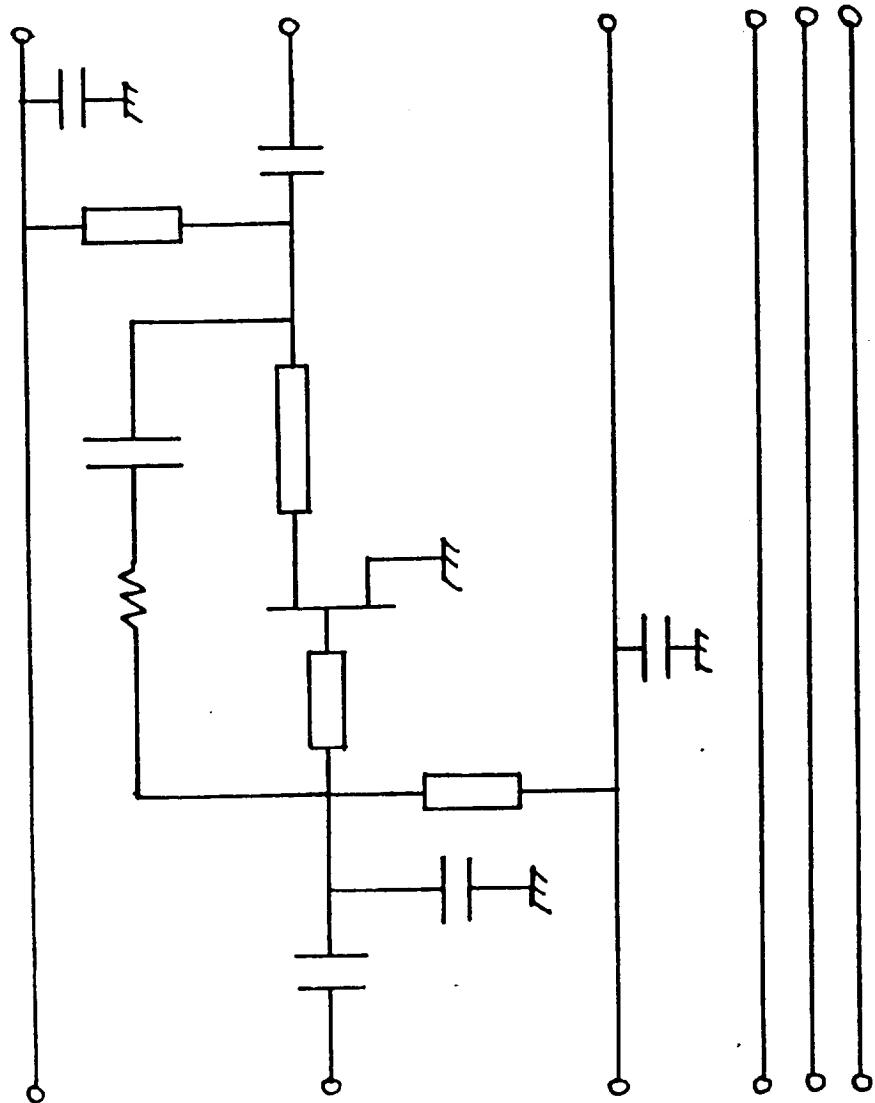


Figure 3.4-1) Schematic Diagram of the Single Stage Buffer Amplifier

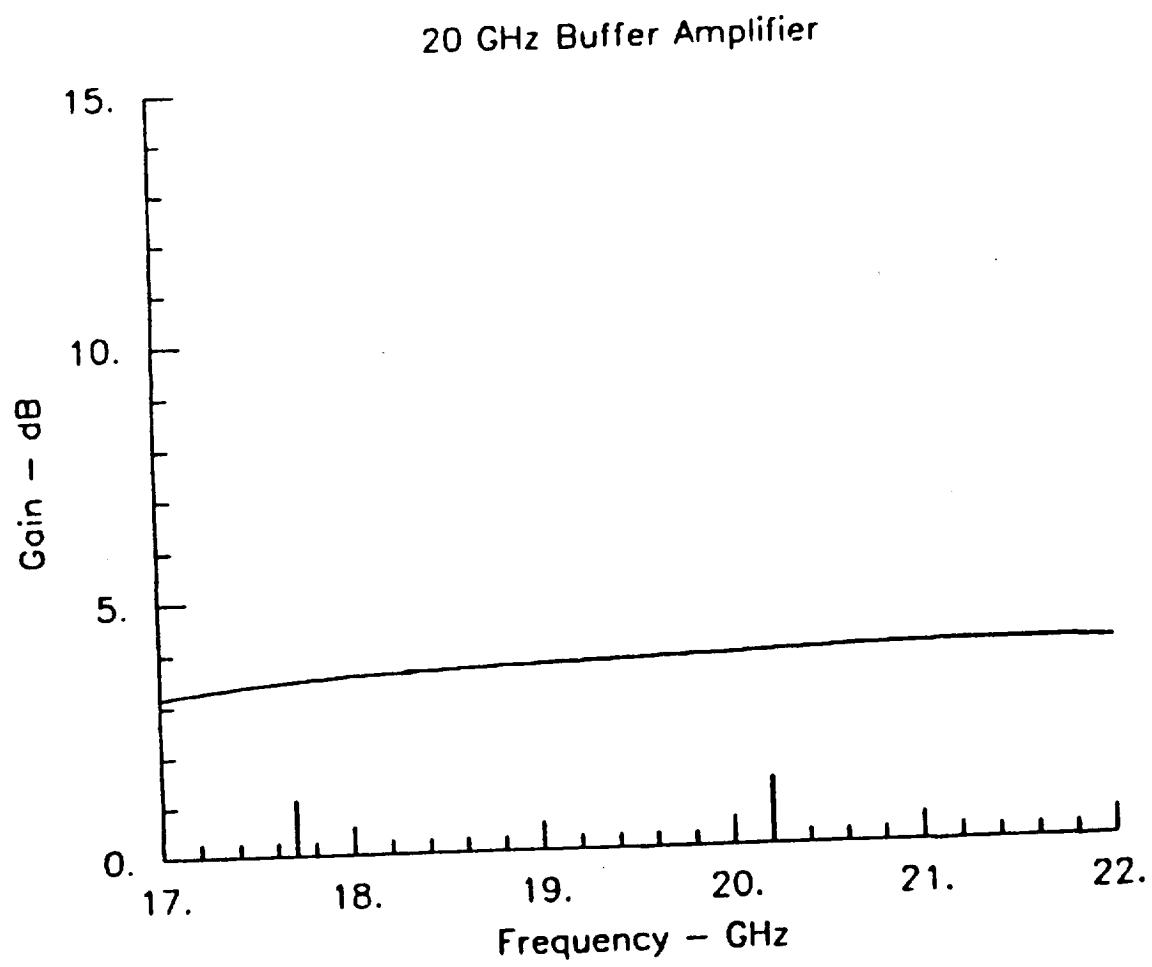


Figure 3.4-2) Predicted Performance of the Single Stage Buffer Amplifier

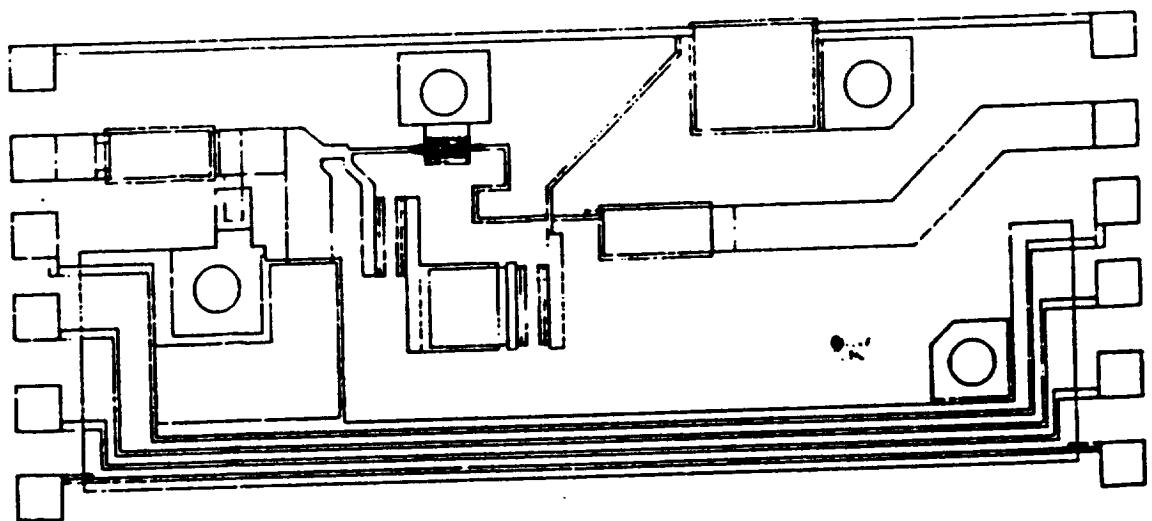


Figure 3.4-3) Composite Pen Plot of the Single Stage Buffer Amplifier

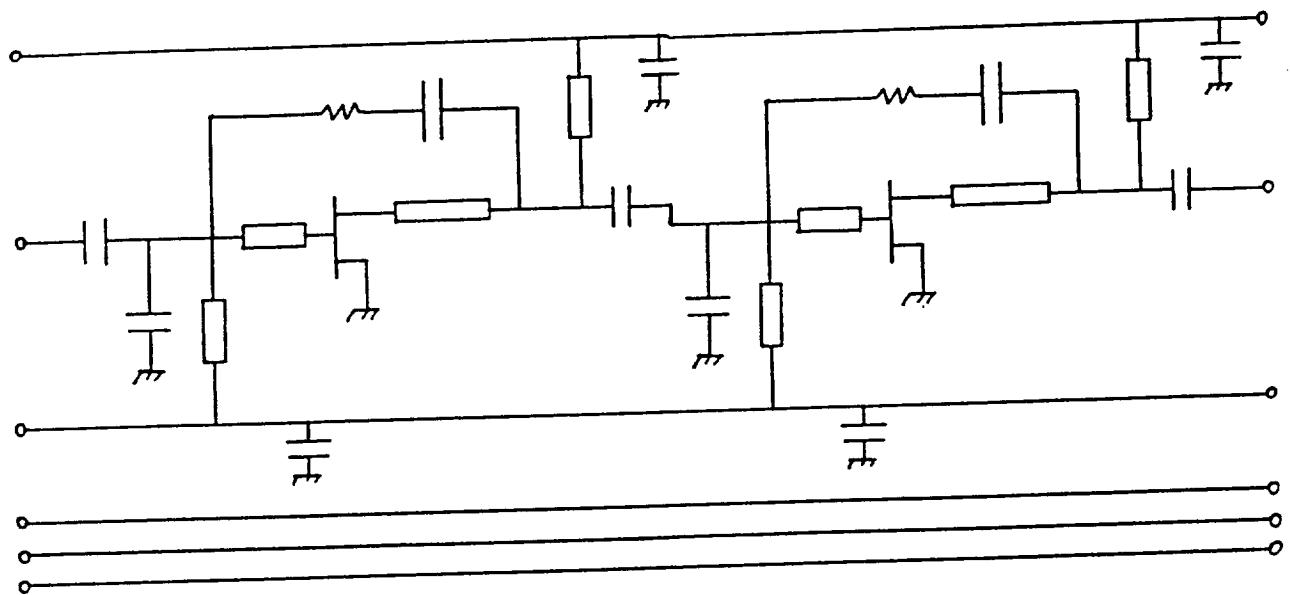


Figure 3.4-4) Schematic Diagram of the Two Stage Buffer Amplifier

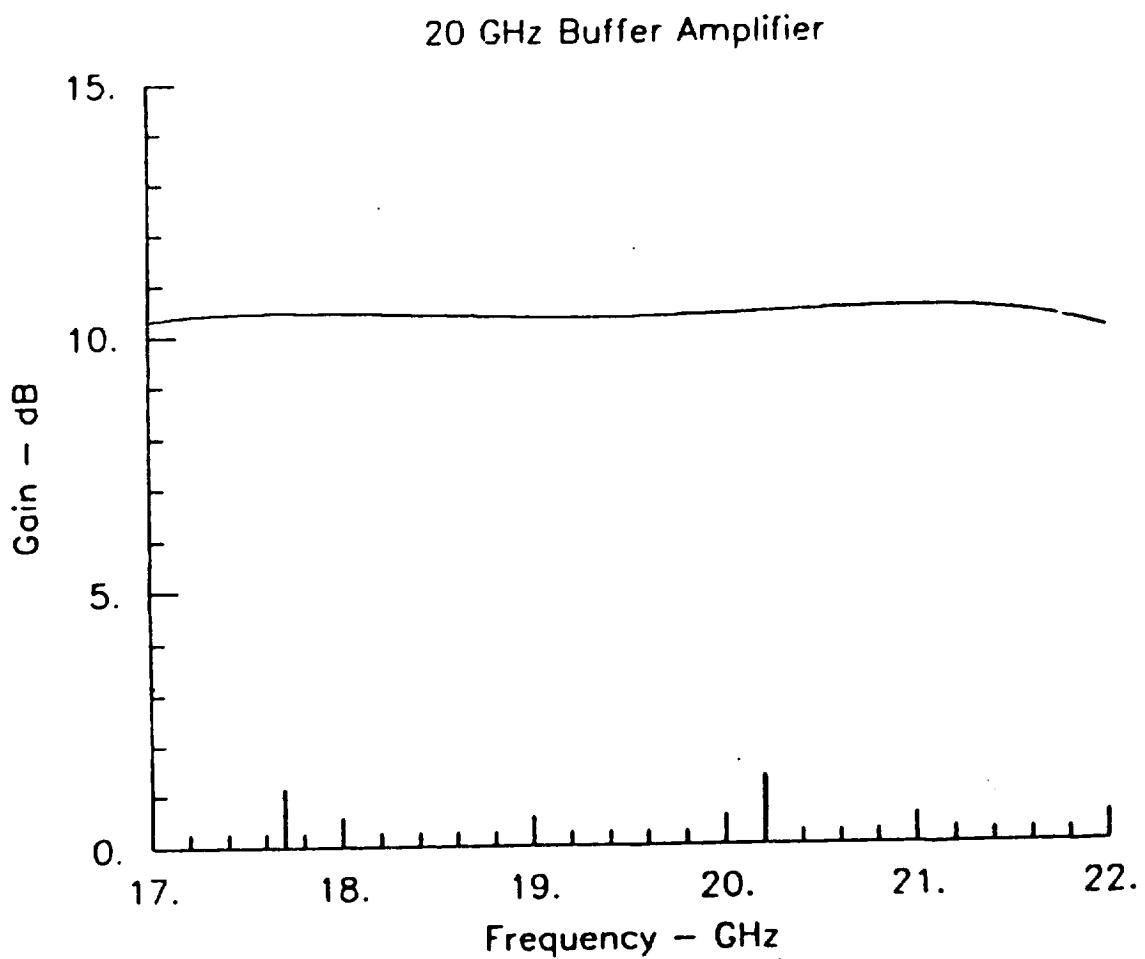


Figure 3.4-5) Predicted Performance of the Two Stage Buffer Amplifier

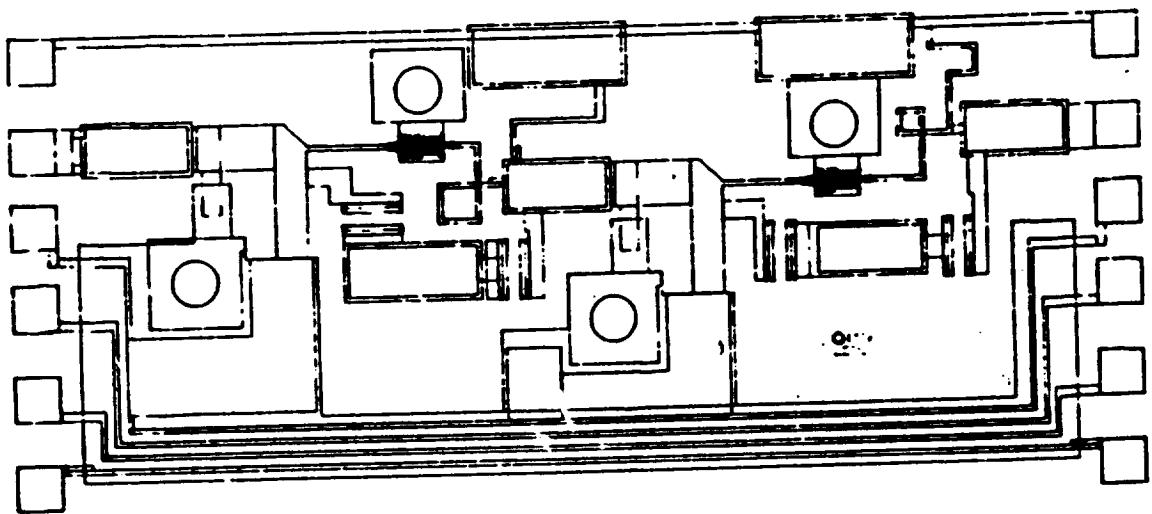


Figure 3.4-6) Composite Pen Plot of the Two Stage Buffer Amplifier

3.5) Control Circuitry

The major thrust of this program was the demonstration of proof of concept for the RF switch matrix, thus the development of control circuitry was only considered to the extent necessary for support of the testing of the RF switch matrix. Under a separate program, NASA Lewis Research Center developed a switch matrix control box which was utilized extensively throughout this program to provide the primary and inverted signals necessary to turn the various crosspoints "on" and "off". GaAs inverters have been previously designed at MMInc. to eliminate the need for the inverted signal, and a schematic of this circuitry is shown in Figure 3.5-1. The predicted transfer curve of the circuit shown in Figure 3.5-1 is presented in Figure 3.5-2, and a composite pen plot of nine of these circuits is shown in Figure 3.5-3.

With continuing fabrication and packaging experience, however, it is becoming apparent that it is preferable to eliminate this low efficiency heat generating circuitry from the interior of the GaAs chip and instead retain the inverted control line inputs to the RF switch matrix. Any realistic systems application of the RF switch matrix will necessarily contain a rather complex integral control circuit (fabricated with Si integrated circuit technology), and this circuitry is much better adapted for supplying the inverted signal if it is not already present.

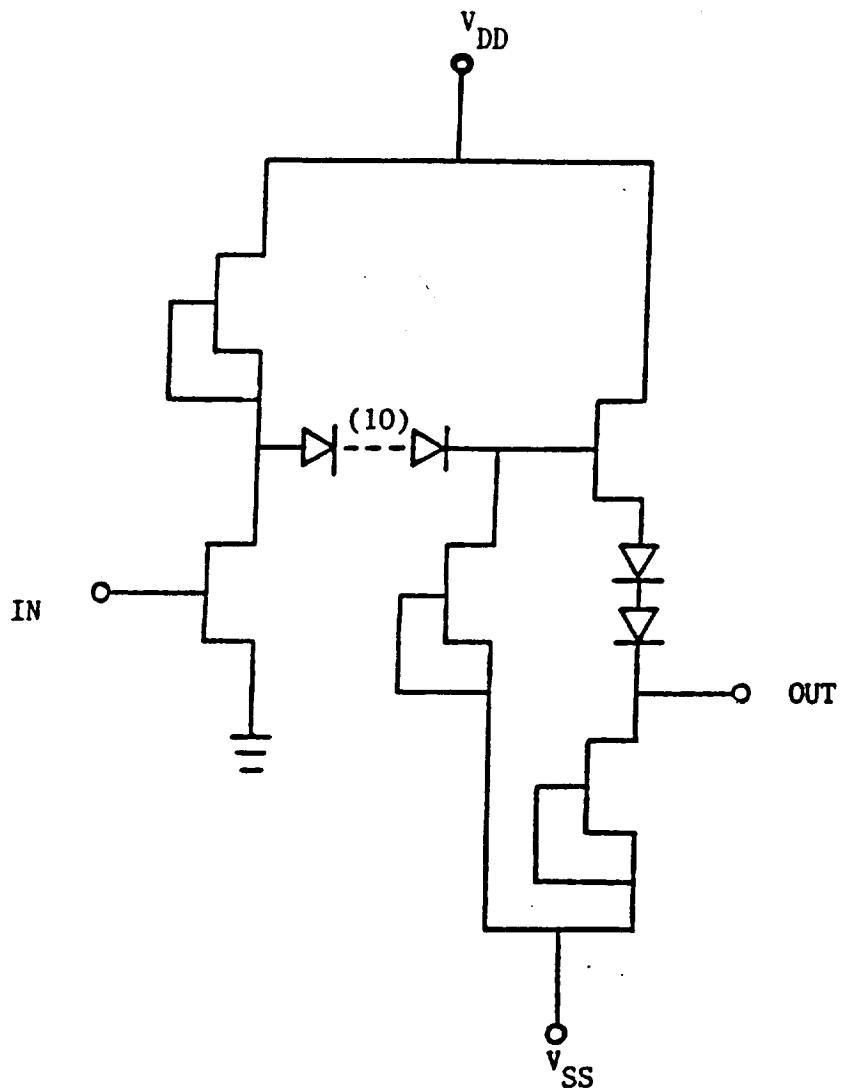


Figure 3.5-1) Schematic of a Single Monolithic Control Circuit.

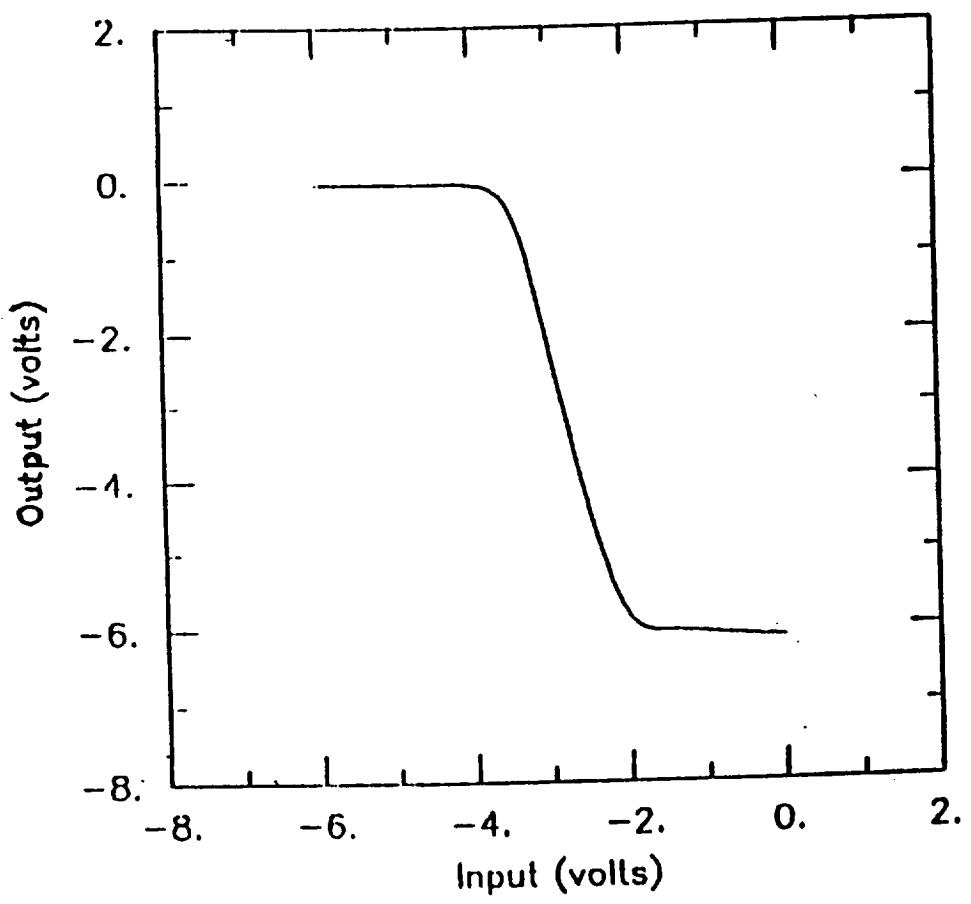
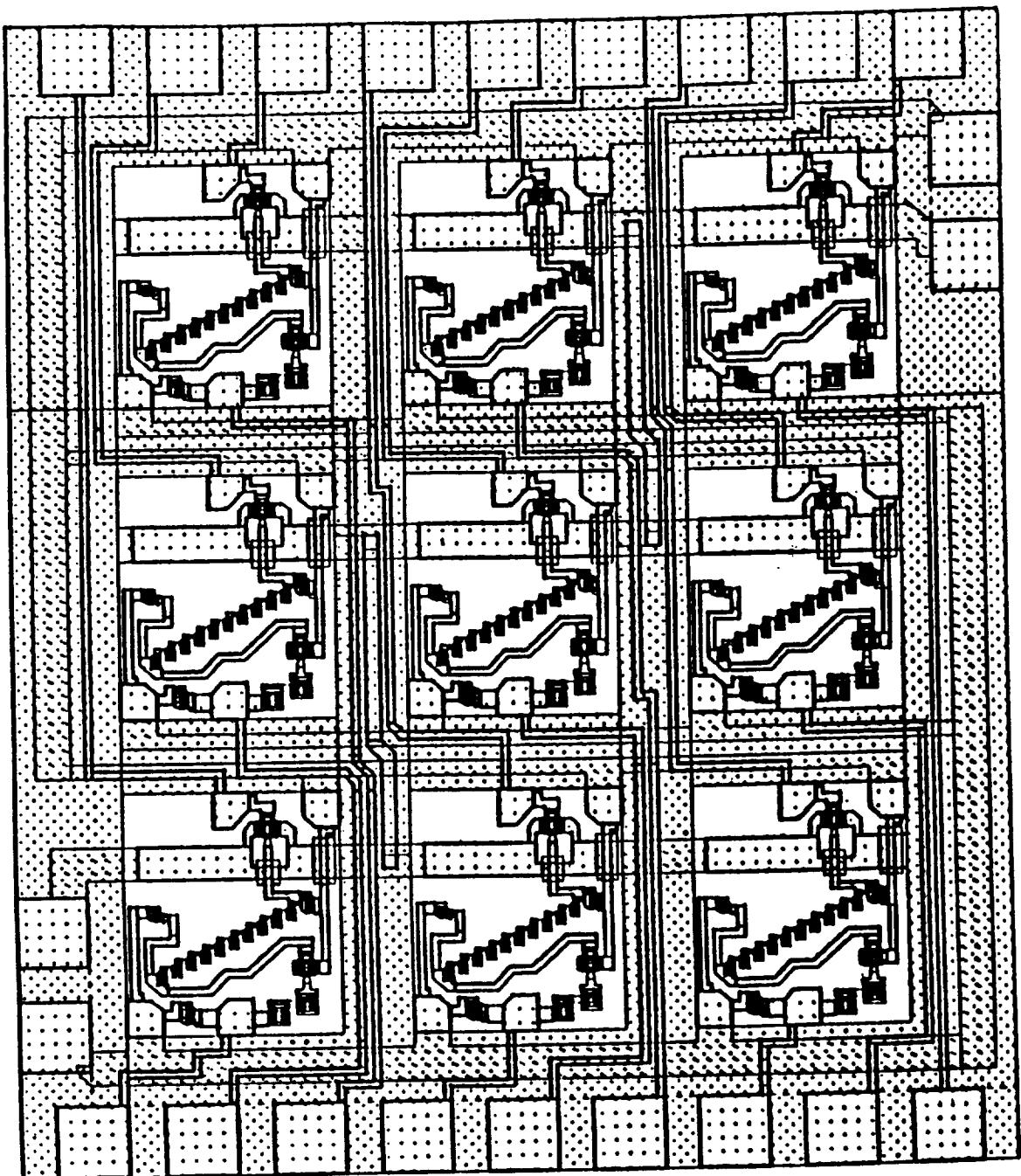


Figure 3.5-2) Voltage Transfer Curve for the Monolithic Control Circuit

Figure 3.5-3) Composite Pen Plot of the Nine Inverter Control Circuit.



3.6) High Isolation Package Design

An important consideration for large switch matrix subsystems is the implementation of the monolithic matrix interconnection/packaging scheme. The approach selected for the RF switch matrix package utilized in this program was based heavily on a previously developed IF switch matrix package which operated over the 3.5 to 6 GHz band. Although the external configuration and the chip mounting scheme are identical for the 20 GHz package, the internal RF feed network had to be completely redesigned to maintain the excellent isolation inherent in the matrix design. All microstrip lines were replaced with fully shielded micro-coaxial transmission lines, and the shields were individually grounded at both the SMA connectors and at the chip interface to minimize common mode inductive feed through effects. As a result of these precautions, and the high isolation of the MMIC chip, measured performance is limited by the interconnection between the package and the MMIC, and by parasitic coupling to the low frequency switch matrix control lines.

4) RF SWITCH MATRIX FABRICATION AND ASSEMBLY

4.1) MMIC Fabrication

As previously described, the gate length selected for the passive switching FETs is 1.5 microns. This relatively long gate length, which is well above the half micron geometries achievable with MMInc.'s standard process, was selected to enhance yield of the complex switch matrix MMIC. Therefore the front end processing presented no unusual requirements other than the necessity for extremely high yield due to high circuit complexity. As originally anticipated the yield requirement turned out to be difficult to achieve, however with the experience gained from a previous IF switch matrix program, this obstacle was overcome sufficiently to meet the program requirements. Further work is, however, required in the area of circuit yield to fabricate still larger monolithic RF switch matrix chips.

The FET active layer is formed by "flash annealed" ion implanted Si⁺ in GaAs, which is routinely used for all discrete and MMIC processing at MMInc. The same active layer is utilized to form resistors. This annealing process is a key step in switch matrix fabrication. All the parameters relevant to device performance are affected: carrier activation, mobility, and the active layer/substrate interface. Perhaps most important for the switch matrix, very high device uniformity across the 3-inch wafer, as well as from wafer to wafer, is attainable with MMInc.'s proprietary "flash annealing" technique.

After the active regions have been defined, ohmic contact areas are formed with deposition of a Au-Ge eutectic and a Ni overlay followed by alloying at a temperature of 450°C. The gates are typically defined using positive resist and mid-UV contact photolithography followed by a lift-off technique after metallization. The gate metallization system used at MMInc. is Ti/Pt/Au, which forms a stable Schottky barrier on GaAs. The thickness of the lifted gates is typically 0.7 micron. After

the gate processing, a Ti/Au overlay metallization step provides the first level of circuit interconnection.

In order to minimize degradation of FET characteristics during further processing, and to provide scratch protection, the exposed active regions are then immediately covered by defining protective regions of low dielectric constant material. This is also used as the insulator for cross-over structures. High dielectric constant material is also deposited to form metal-insulator-metal (MIM) capacitors on the MMIC, needed for the buffer amplifier circuitry. A plated metallization layer then provides an additional low loss interconnection, which is needed for the high performance switch matrix.

For low inductance on-chip grounding, through substrate via connections are used. Via holes are formed after the wafers have been thinned to the final thickness of 5 mils (125 microns), and the backside of the wafer is metallized to form the ground plane for the microstrip circuitry. Individual chips are obtained following dicing.

A photograph of the 4.9 X 4.9 millimeter RF 3 X 3 switch matrix after completion of all front end processing is shown in Figure 4.1-1. The regular array of crosspoints is clearly visible, as are the bonding pads for the RF signal lines and DC control lines. A photograph of an entire 2 inch GaAs wafer of RF switch matrices prior to final dicing is shown in Figure 4.1-2. The regular array of VLSI chips is clearly visible, as are the test structures and alignment "drop-outs". Finally, Figure 4.1-3 shows a photograph of a completed buffer amplifier chip ready for assembly into the package.

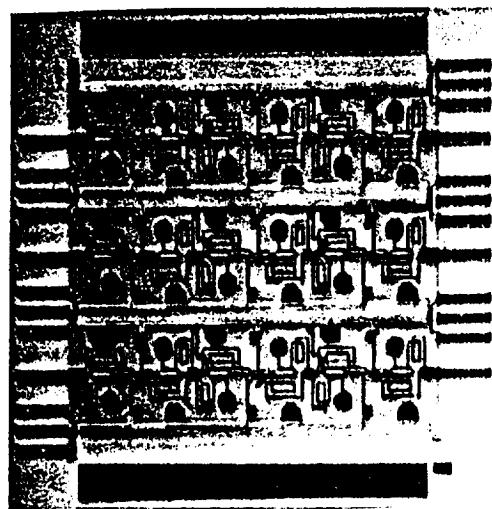


Figure 4.1-1) Photograph of the 4.9 x 4.9 Millimeter
3 x 3 Monolithic GaAs RF Switch Matrix
Chip

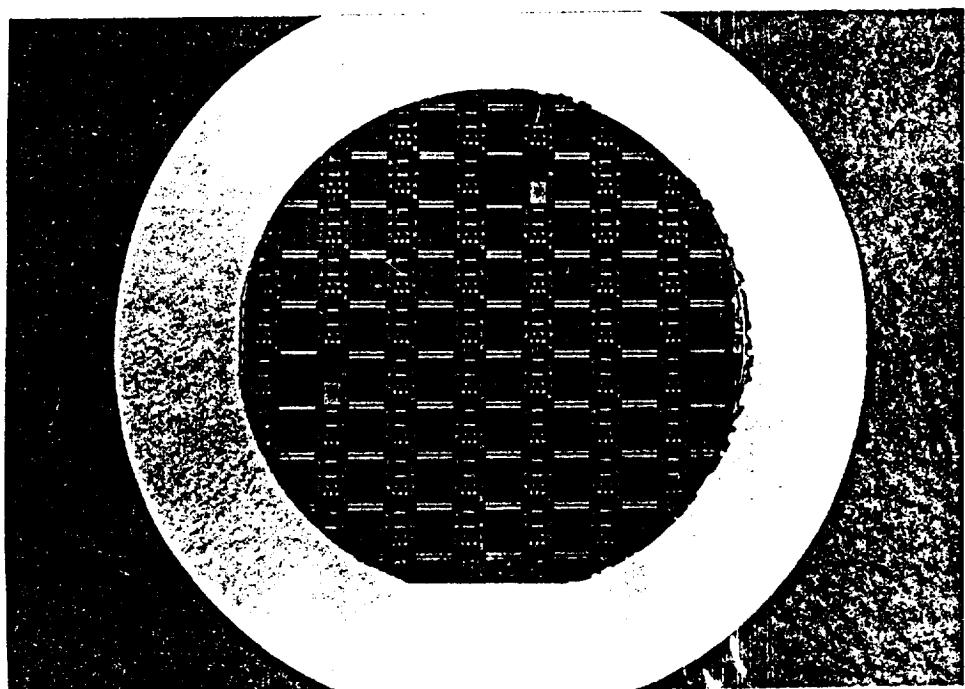


Figure 4.1-2) Photograph of a Full 2 Inch GaAs Wafer Containing an Array of 3 X 3 RF Switch Matrices

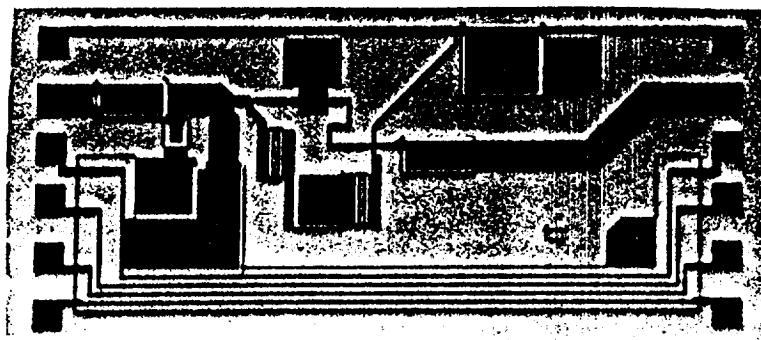


Figure 4.1-3) Photograph of a 20 GHz Buffer Amplifier Ready for Final Integration

4.2) Monolithic Switch Matrix/Package Integration

The integration of the GaAs RF switch matrix MMIC and MMInc.'s package are a crucial aspect of the design effort. Without careful attention to this aspect of the switching subsystem, excellent inherent chip performance could easily be destroyed by the package in the final implementation. As is evident below, however, further efforts in this area would be beneficial.

Figure 4.2-1 is a photograph of the sealed package delivered to NASA Lewis Research Center. This circuit includes all necessary bias and RF shielding circuitry. The 2.1 X 2.1 X 0.4 inch package size (excluding connectors) is determined by the minimum allowable spacing between SMA connectors rather than the MMIC switch matrix chip size.

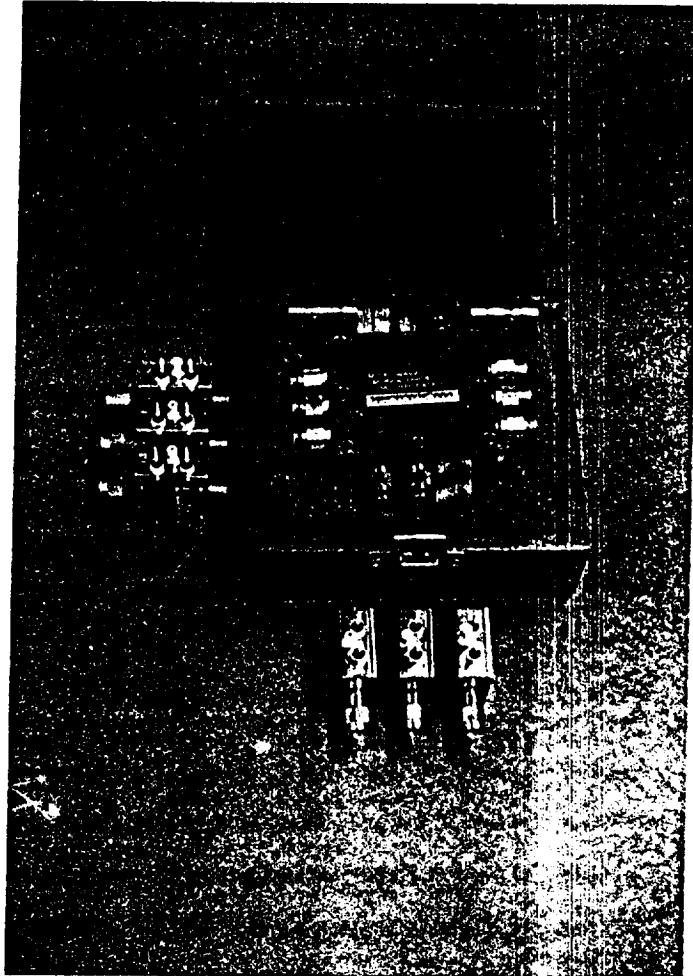


Figure 4.2-1) Photograph of Sealed Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

5) RF SWITCH MATRIX CHARACTERIZATION

Characterization of the switch matrix is a multi-step process due to the complexity of the system. The MMIC switch matrix can not compensate for signal leakage in the housing, therefore the housing must be characterized to allow interpretation of the measured MMIC subsystem response. Only in this manner is it feasible to diagnose and correct any packaging problems encountered. A single crosspoint is then characterized in the housing, followed by characterization of the full 3×3 switch matrix.

The following sections describe each of these steps in detail, and present the results obtained for each case.

5.1) Characterization of the High Isolation Package

Package characterization consisted of isolation measurements between all relevant SMA connectors at various steps of the housing/package assembly. However, prior to package characterization it is necessary to ascertain the noise floor of the measurement system. Therefore the "isolation" of two shielded and well separated 50 ohm terminations was first evaluated. Results of this measurement are shown in Figure 5.1-1, which shows a measurement limit in the 85 dB range across the 17.7 to 20.2 GHz band. Also shown in the figure is a measurement trace for a 59 dB reference pad to verify that the calibration is correct in the range of interest.

Typical results of the package measurement are shown in Figures 5.1-2 and 5.1-3. For the first case, the MMIC switch matrix chip and the DC and RF feed ribbons were omitted from the package, however the coaxial feeds from the SMA connectors to the position of the RF switch matrix chip were included (without termination at the chip interface). Therefore all RF lines were open circuited, which represents a worst case evaluation of package isolation. As shown in Figure 5.1-2, package isolation was excellent at a level better than 60 dB across the band of interest.

Figure 5.1-3, however, shows the measured performance after addition of the DC and RF feed ribbons, which were still unterminated. As indicated in the figure, isolation is typically in the 30 dB range, which will clearly limit ultimate measured performance for the 3 X 3 RF switch matrix. Performance would be expected to improve under the terminated operating conditions encountered with an MMIC chip in place, and indeed as shown in the following sections better performance has been obtained for the final, fully functional unit. None the less, this aspect of the current RF switch matrix package design is believed to be the isolation limiting factor for the current design.

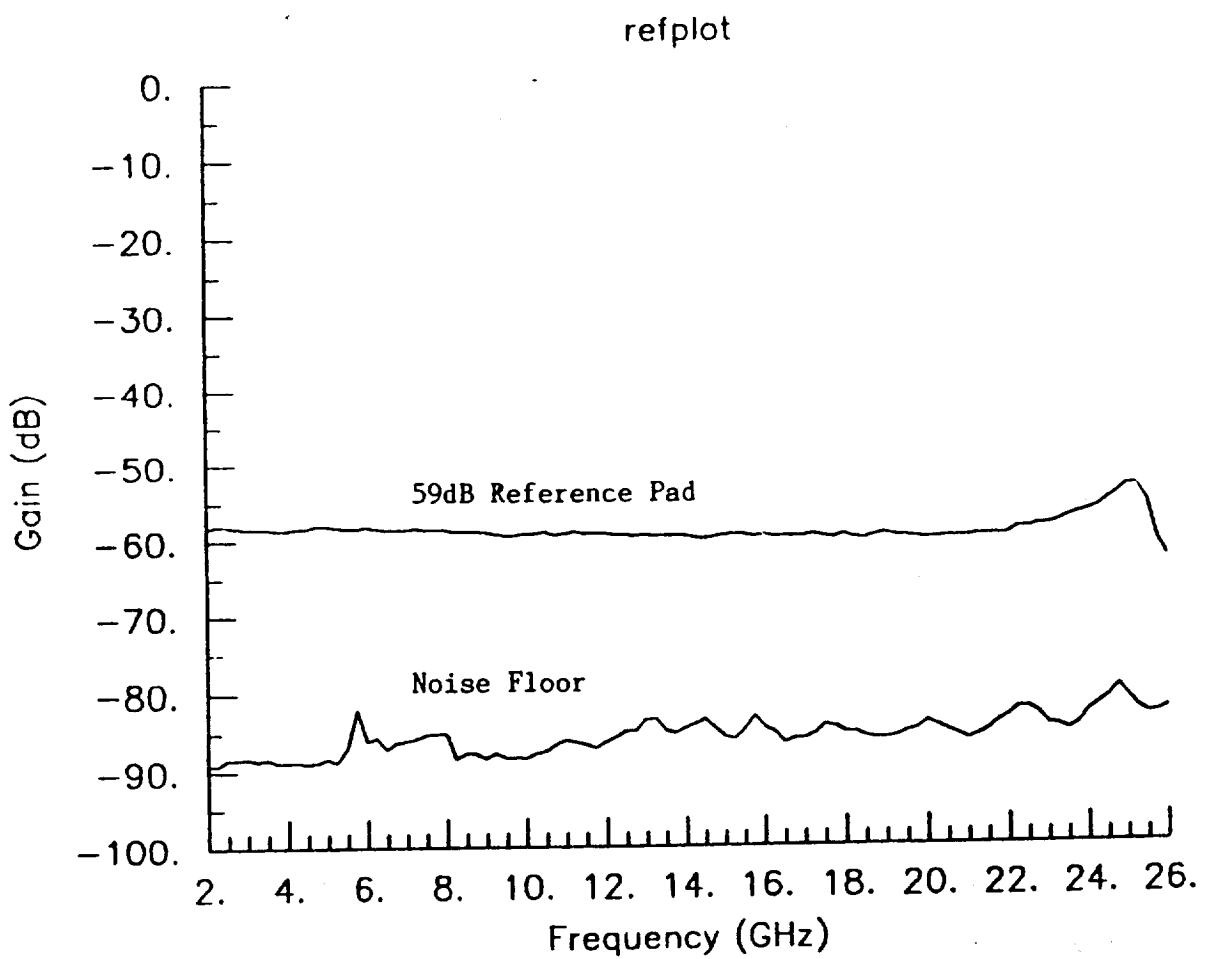


Figure 5.1-1) System Noise Floor Measurement based on Shielded and Well Separated 50 Ohm Terminations

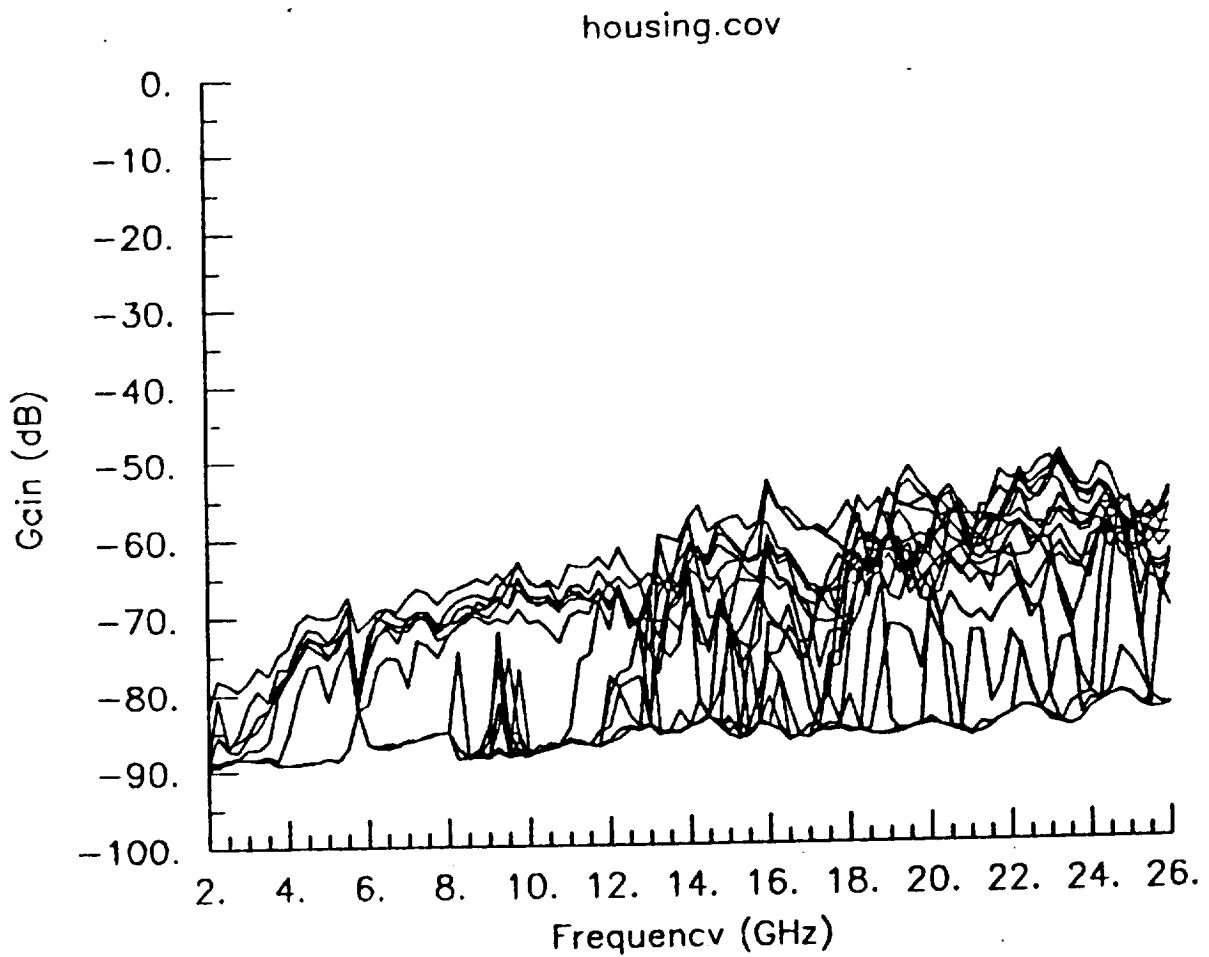


Figure 5.1-2) Measured Package Isolation with Coaxial Feeds

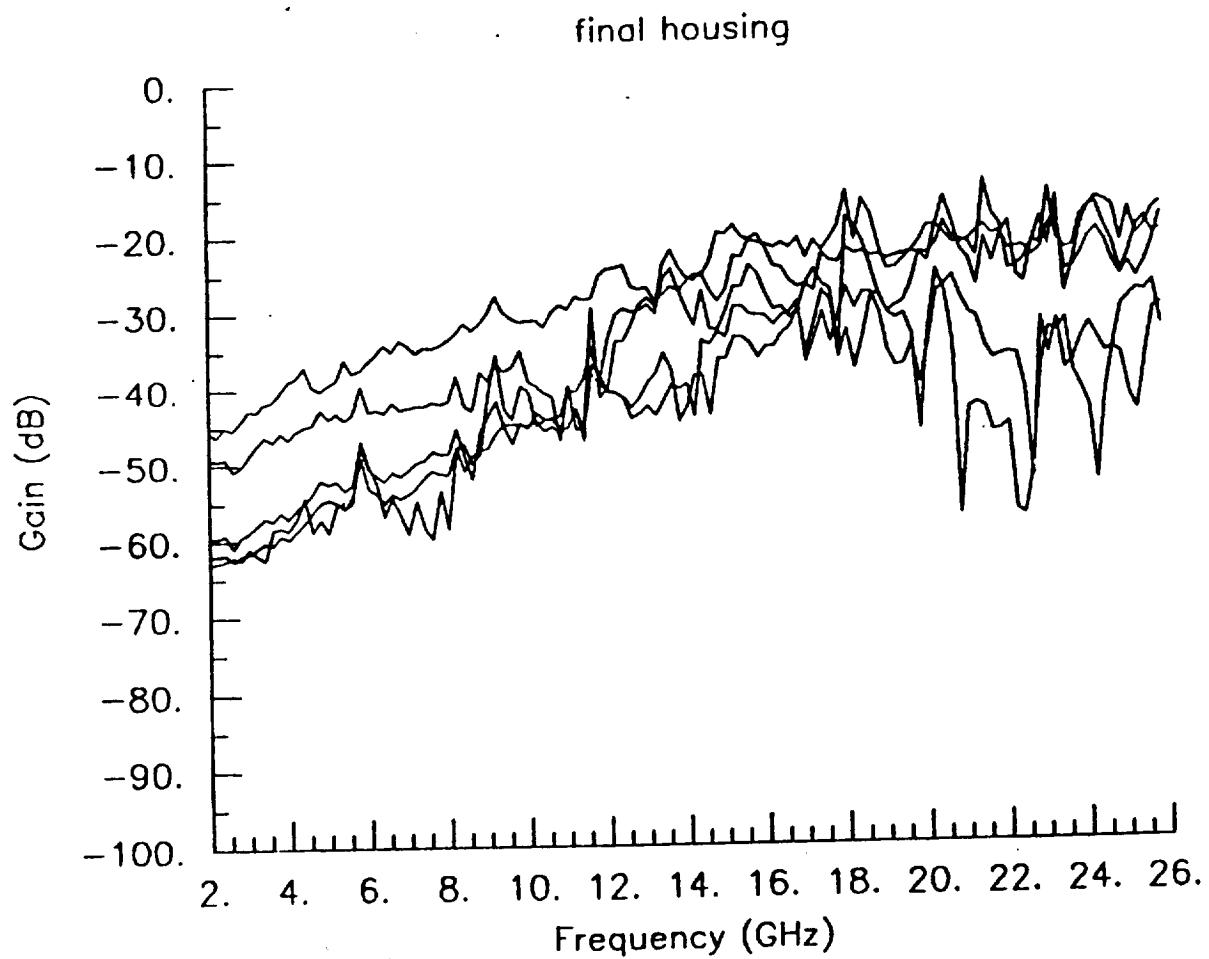


Figure 5.1-3) Measured Package Isolation with Coaxial Feeds and Ribbon Interconnect Circuitry

5.2) Single Crosspoint Frequency Response

A single crosspoint is periodically placed across the mask tool set used to fabricate the 3 X 3 monolithic RF switch matrix. Therefore it is available for diagnostic purposes and to separate circuit effects due to the crosspoint proper from interactions between crosspoints. Since it is fabricated in parallel with the full 3 X 3 matrix, it is representative of the crosspoints in the RF switch matrix itself. This section presents measurements on the single crosspoint.

With the crosspoint mounted on a standard carrier, all through substrate vias are grounded and the through (port 1 to port 3) insertion loss and isolation can in principle be characterized. Results of this characterization are summarized in Figure 5.2-1, which shows the measured insertion loss and gain for the single crosspoint. The test fixture insertion loss of approximately 1 dB has not been removed from the data shown.

Although some indication of insertion loss can be obtained from this data, measured isolation is meaningless due to the relatively high leakage of the standard test fixture at 20 GHz. It would in principle be possible to fabricate a special fixture/package similar to that used for the full 3 X 3 matrix, however it was decided that the available resources could be best applied to the characterization of the full 3 X 3 RF switch matrix.

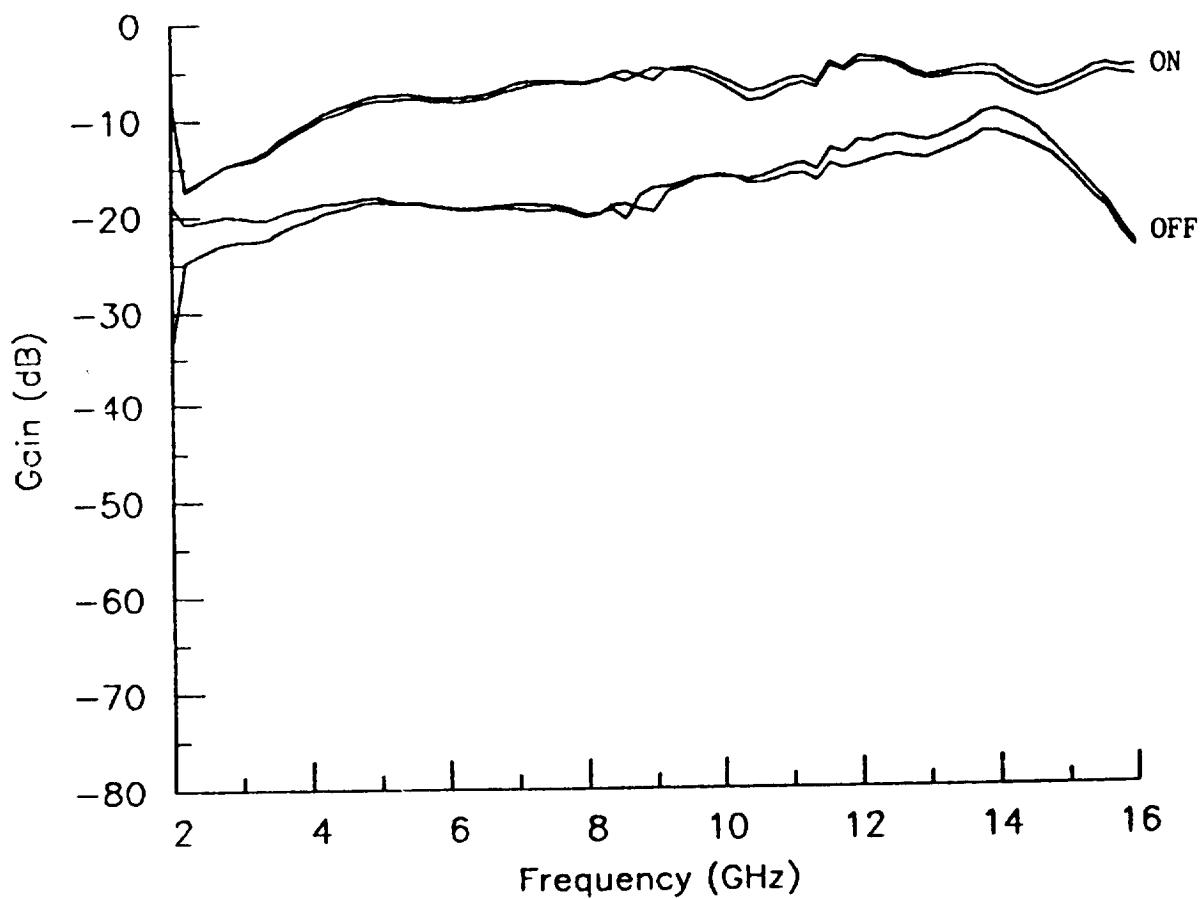


Figure 5.2-1) Measured Insertion Loss and Isolation for a Single Crosspoint in a Standard Test Fixture, Including Test Fixture Insertion Loss

5.3) 3 X 3 Matrix Frequency Response Without Buffer Amps

The standard network analyzer is a two port characterization instrument, however the full 3 X 3 cascadable GaAs monolithic switch matrix is a 12 port. As a result, $11 + 10 + \dots + 1 = 66$ separate RF test lead configurations are needed for a complete evaluation of the 3 X 3 RF switch matrix. For each test lead configuration, there are $2^9 = 512$ possible matrix states, therefore the total number of possible swept frequency measurements is $66 \times 512 = 33,792$. This extensive testing was well beyond the scope of the current program. Even the moderate degree of testing reported below required automation via the NASA provided test box described in Appendix C and a modified version of MMInc.'s automatic network analyzer software.

To provide a concise description of both the RF test lead configuration and the switch matrix control setting, the following five character notation is utilized by MMInc. for captioning and uniquely identifying all swept frequency measurements of the RF switch matrix. All computer files generated retain this identifier for complete traceability, and the notation can be readily extended to much larger matrices. The first two characters of the plot title identify the switch matrix ports connected to the input and output ports of the network analyzer respectively. The port numbering convention was previously summarized in Figure 3.3-1. Note that to retain a single digit representation for each port hexadecimal notation is utilized, i.e. port 10 is A, port 11 is B, and port 12 is C.

The remaining three digits of the identifier completely describe the switch matrix setting. As described in section 3.3, a crosspoint in the through state is considered a binary 0, while that in the bypass state is considered a 1. Each row of three binary bits in the 3 X 3 array is then converted to a decimal number. For example if port 2 is connected to the input of the network analyzer, port 12 is connected to the output, and the matrix is in the bypass state described for Table 3.3-2, then the identifier would be 2C421. Similarly, for the same network analyzer connections with the switch matrix setting as

described for Table 3.3-3, the identifier would be 2C124. Table 5.3-1 summarizes this measurement identification system.

The frequency response of primary interest are the insertion loss of the intended path and the isolation of the unintended paths. Figure 5.3-1 presents a sample of insertion loss plots from several full and partially functional 3 X 3 switch matrices without buffer amplifiers. Note that package insertion loss is included in these measurements, and that the level of insertion loss depends on the number of crosspoints transversed from input to output. A least squares fit to the insertion loss as a function of crosspoints transversed leads to the conclusion that the average crosspoint insertion loss is 2.95 dB per crosspoint and the average package insertion loss is 0.5 dB per feed line. This defines the gains required for the compensating buffer amplifiers of the current switch matrix design and processing sequence.

A selection of isolation measurements, from the same sample of fully and partially functional 3 X 3 switch matrices, is presented in Figure 5.3-2. Note that excellent isolation is attainable over the 17.7 to 20.2 GHz band, limited primarily by the ribbon to ribbon coupling described above. A complete set of data for the delivered 3 X 3 monolithic GaAs RF switch matrix is presented in Appendix A.

It is also interesting to examine out of band performance of the 3 X 3 switch matrix. Figure 5.3-3 shows wideband measured performance for a few selected states of the RF switch matrix delivered to NASA. As predicted due to the resonant switching architecture, the matrix is inoperable well below or above band, however the bandwidth is somewhat larger than originally predicted. This indicates that resonator Q's are not as high as originally anticipated. These plots also indicate that further optimization of the RF switch matrix is possible since it is apparent that the operating frequency for maximum isolation is skewed somewhat to the high end of the band. Furthermore, the fact that insertion loss and isolation do not peak at the same frequency indicates that the through and bypass resonant switches are not yet tuned to exactly the same frequency.

57200

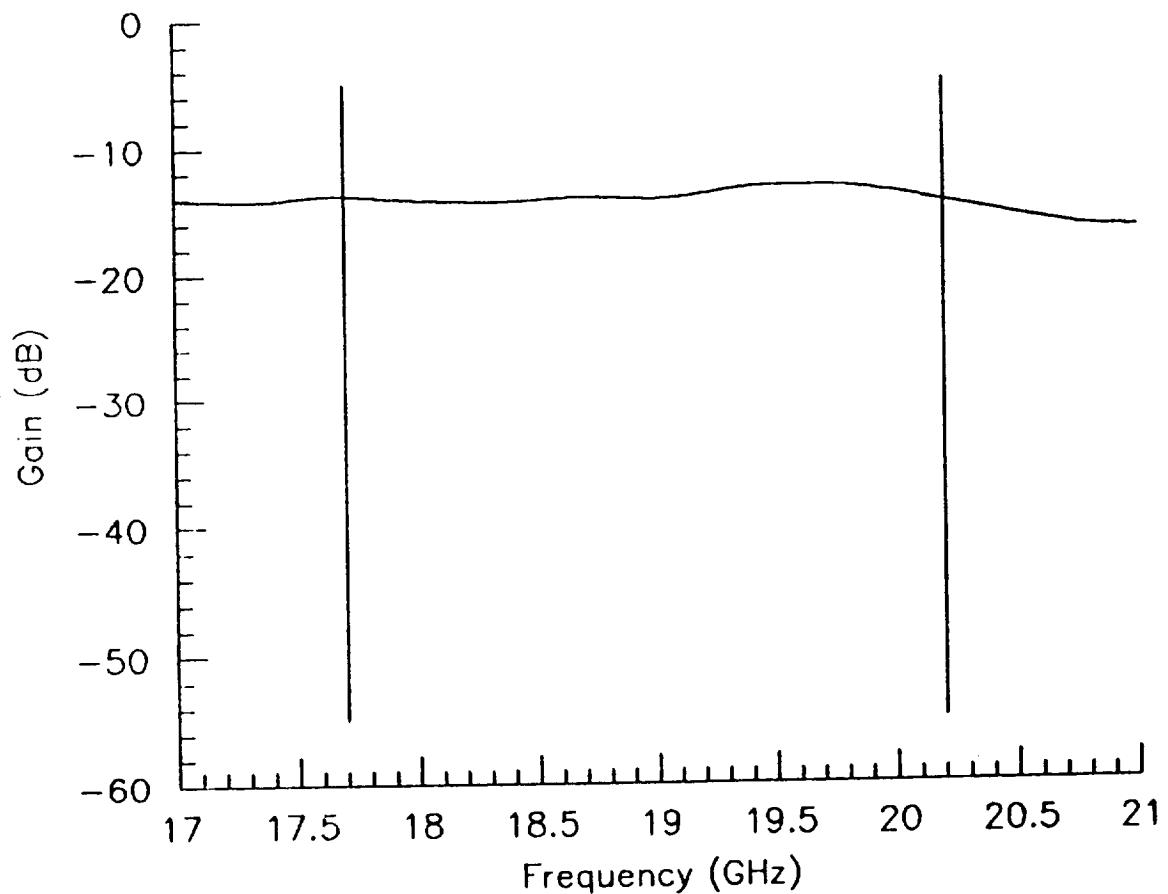


Figure 5.3-1a) Measured Insertion Loss of a Selected Path Through the
Packaged 3 X 3 Monolithic GaAs RF Switch
Matrix without Buffer Amplifiers

68010

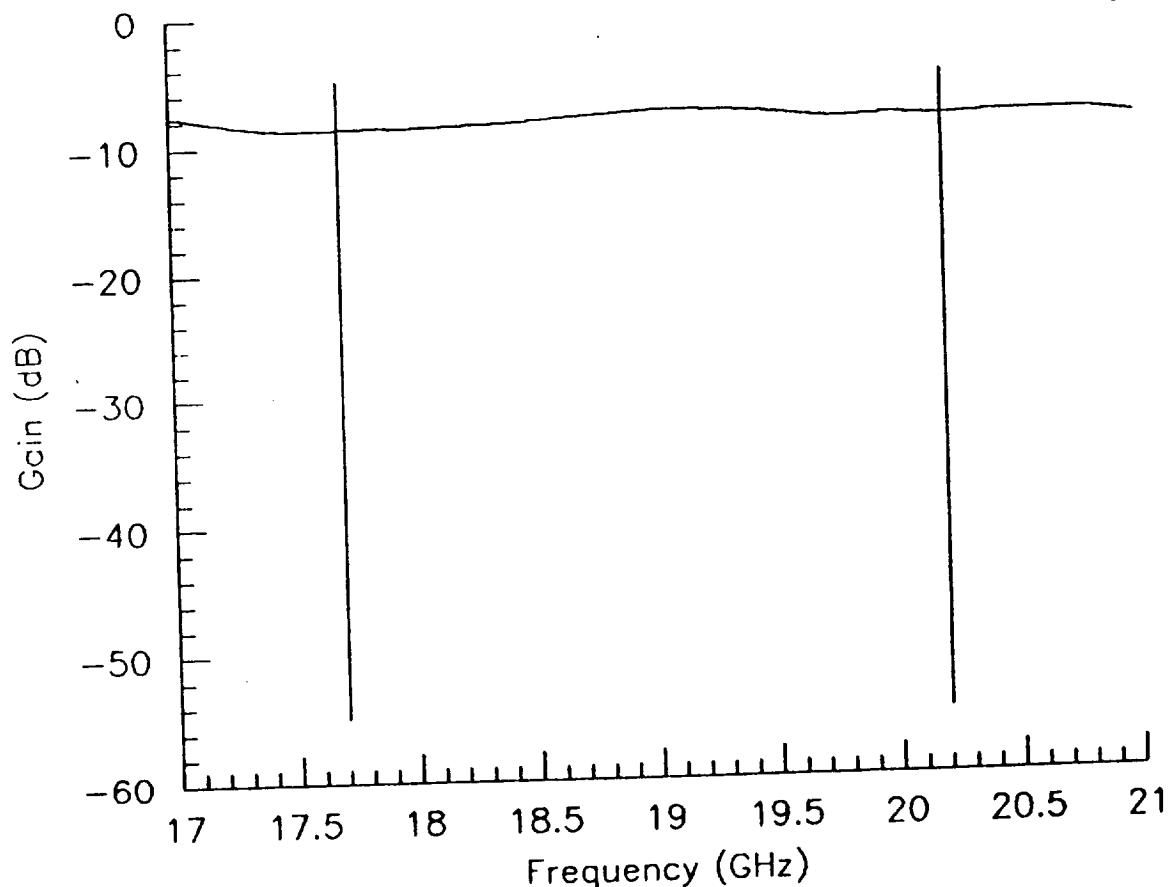
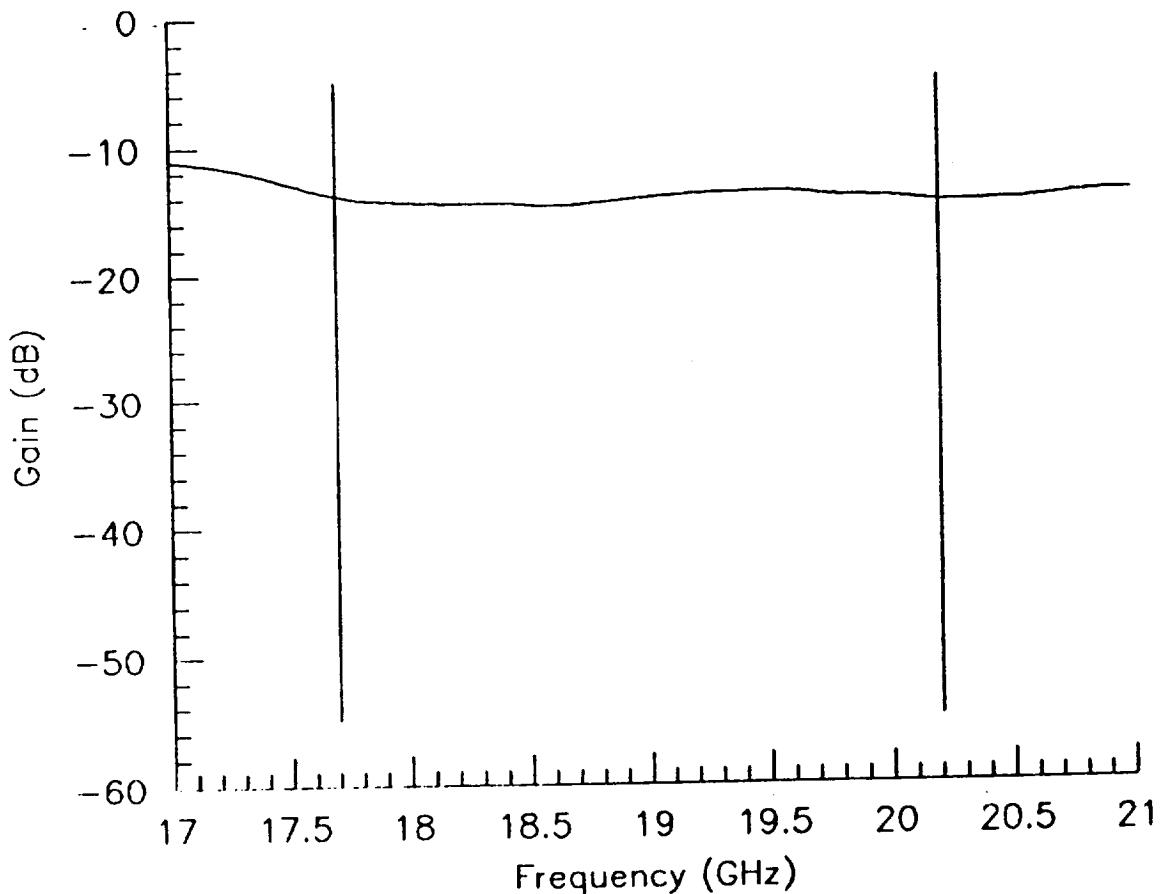


Figure 5.3-1b) Measured Insertion Loss of a Selected Path Through the
Packaged 3 X 3 Monolithic GaAs RF Switch
Matrix without Buffer Amplifiers

1a400



**Figure 5.3-1c) Measured Insertion Loss of a Selected Path Through the
Packaged 3 X 3 Monolithic GaAs RF Switch
Matrix without Buffer Amplifiers**

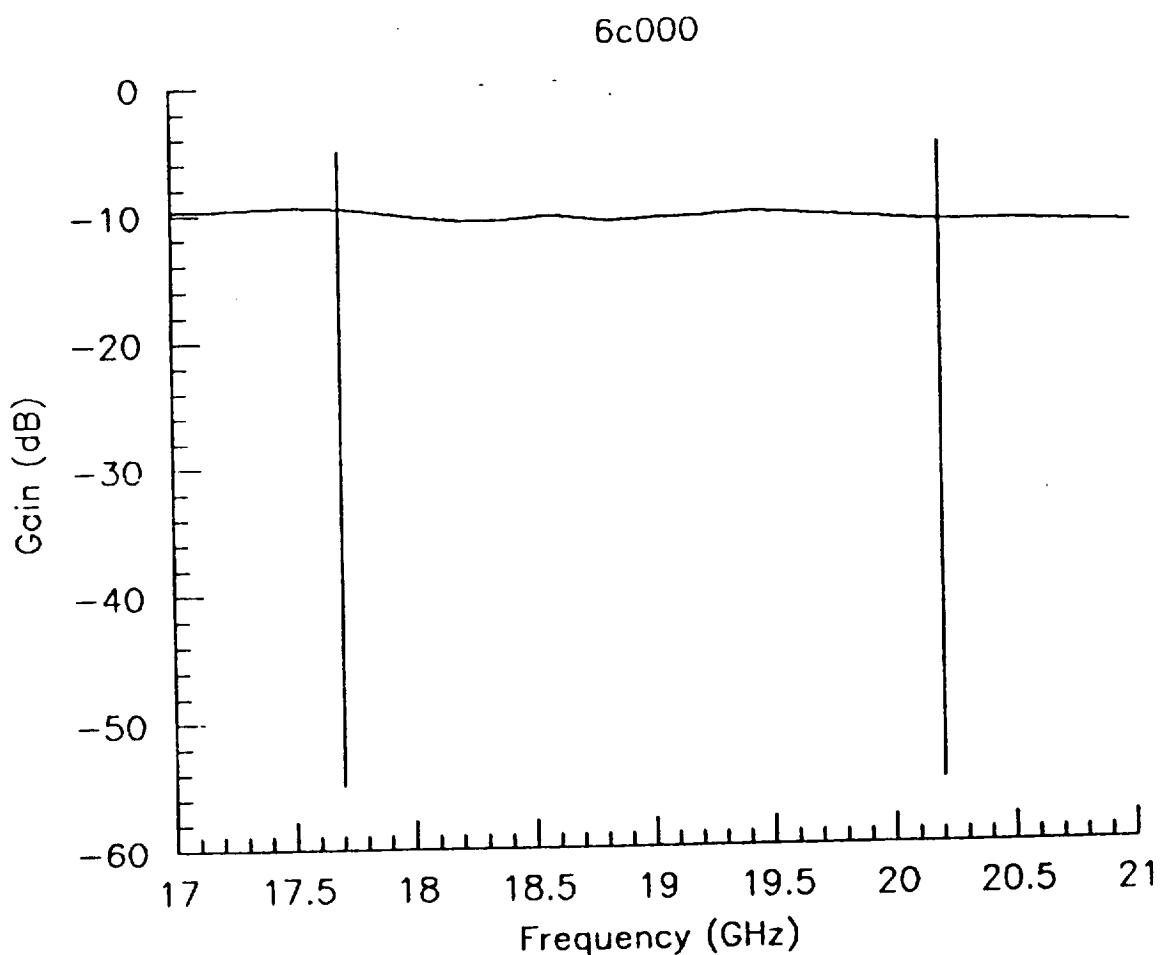


Figure 5.3-1d) Measured Insertion Loss of a Selected Path Through the
Packaged 3 X 3 Monolithic GaAs RF Switch
Matrix without Buffer Amplifiers

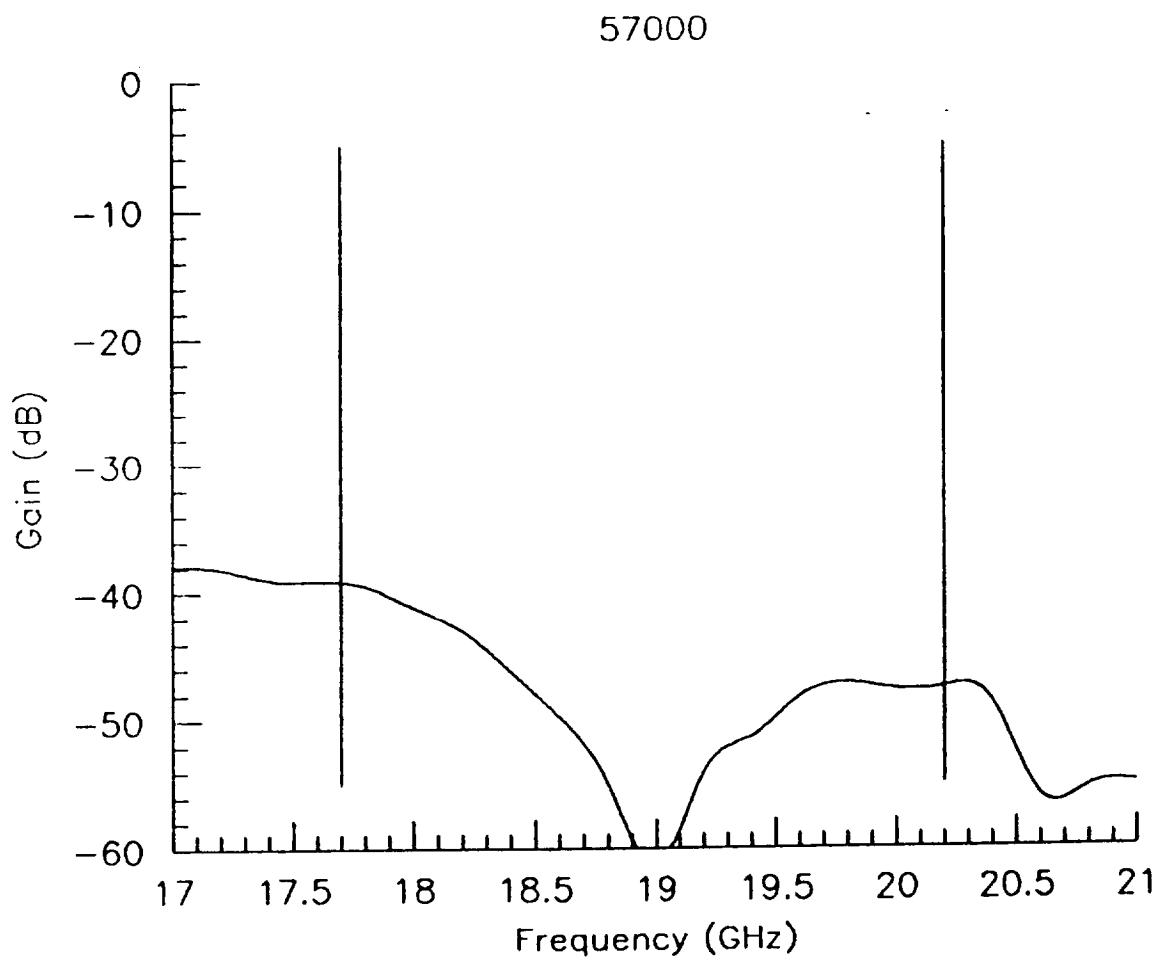


Figure 5.3-2a) Measured Isolation of a Selected Path Through the Packaged 3 X 3 Monolithic GaAs RF Switch Matrix without Buffer Amplifiers

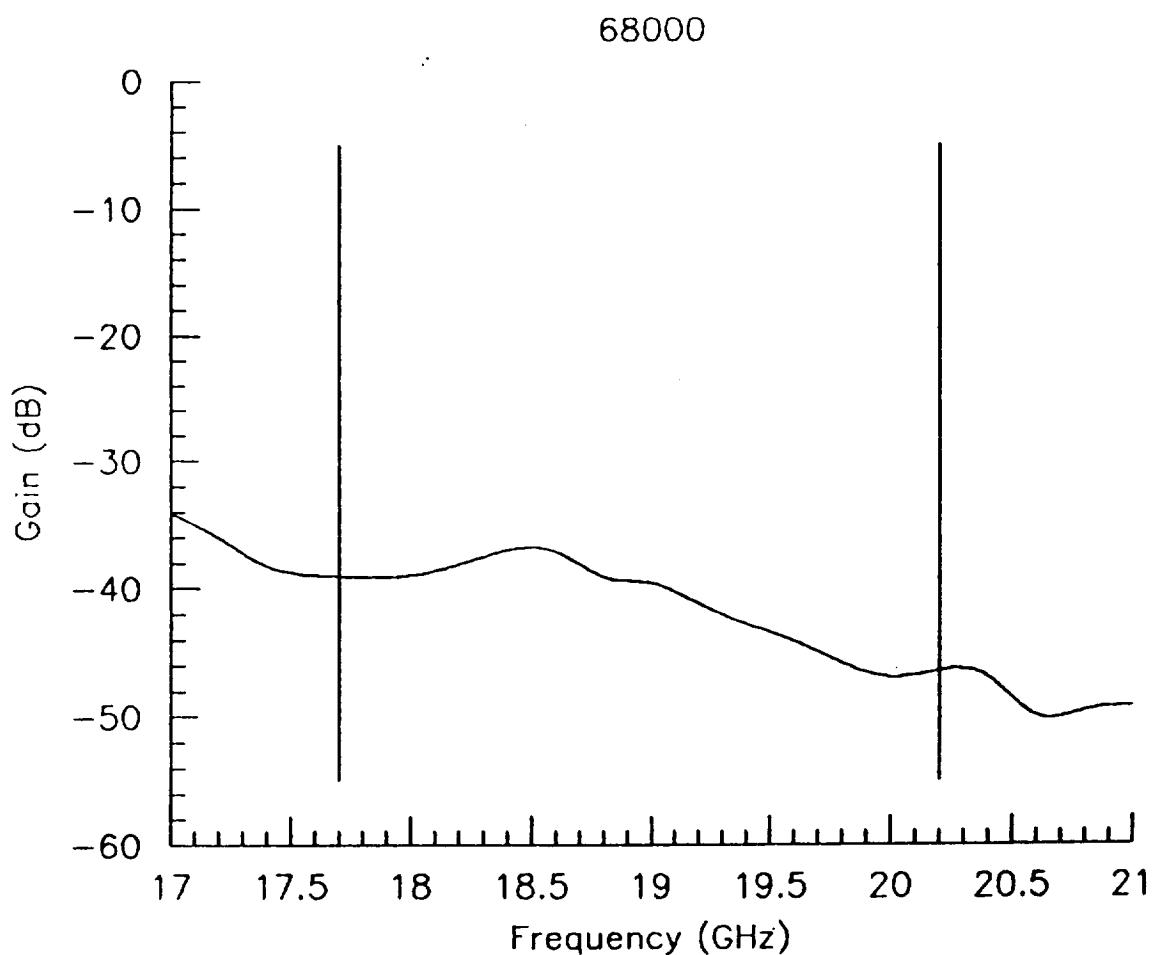


Figure 5.3-2b) Measured Isolation of a Selected Path Through the Packaged 3 X 3 Monolithic GaAs RF Switch Matrix without Buffer Amplifiers

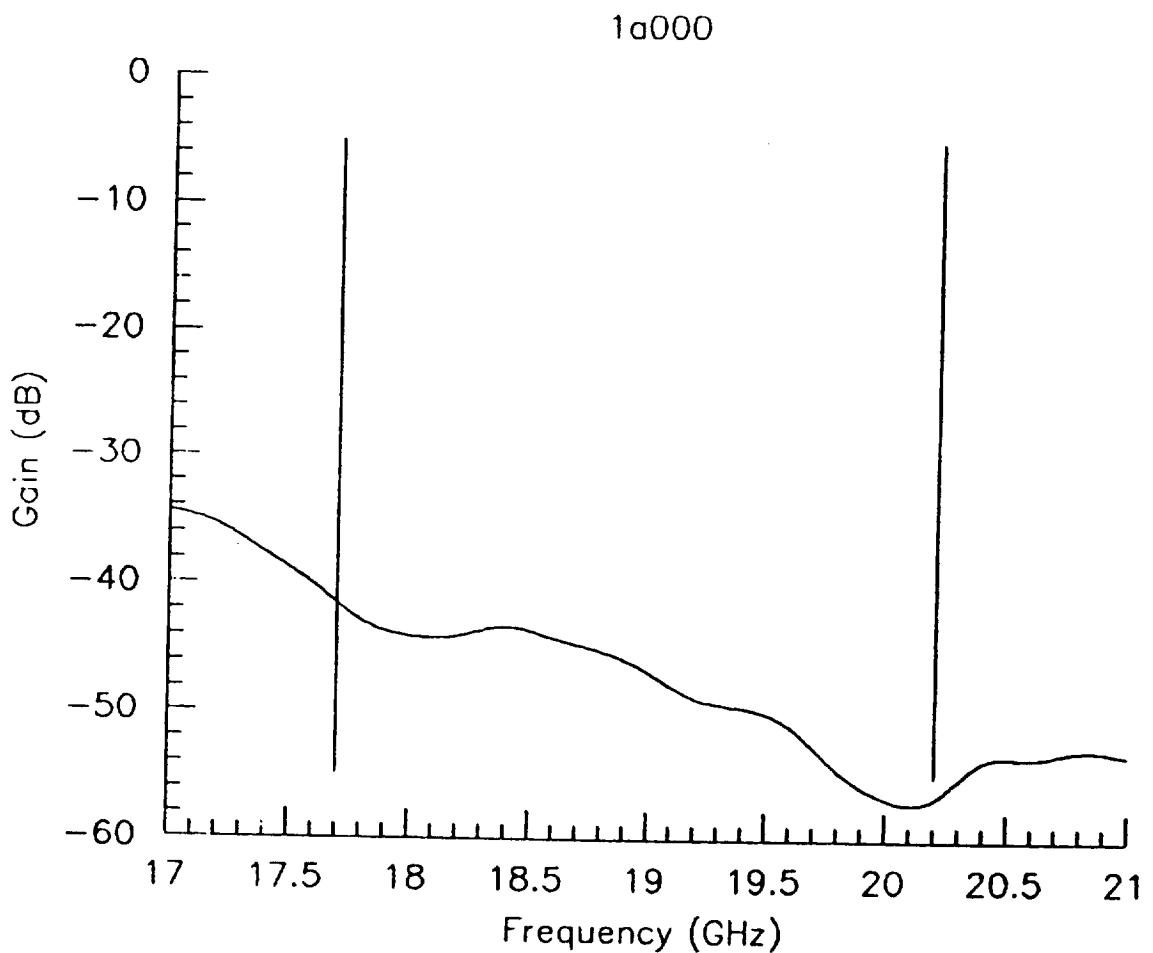
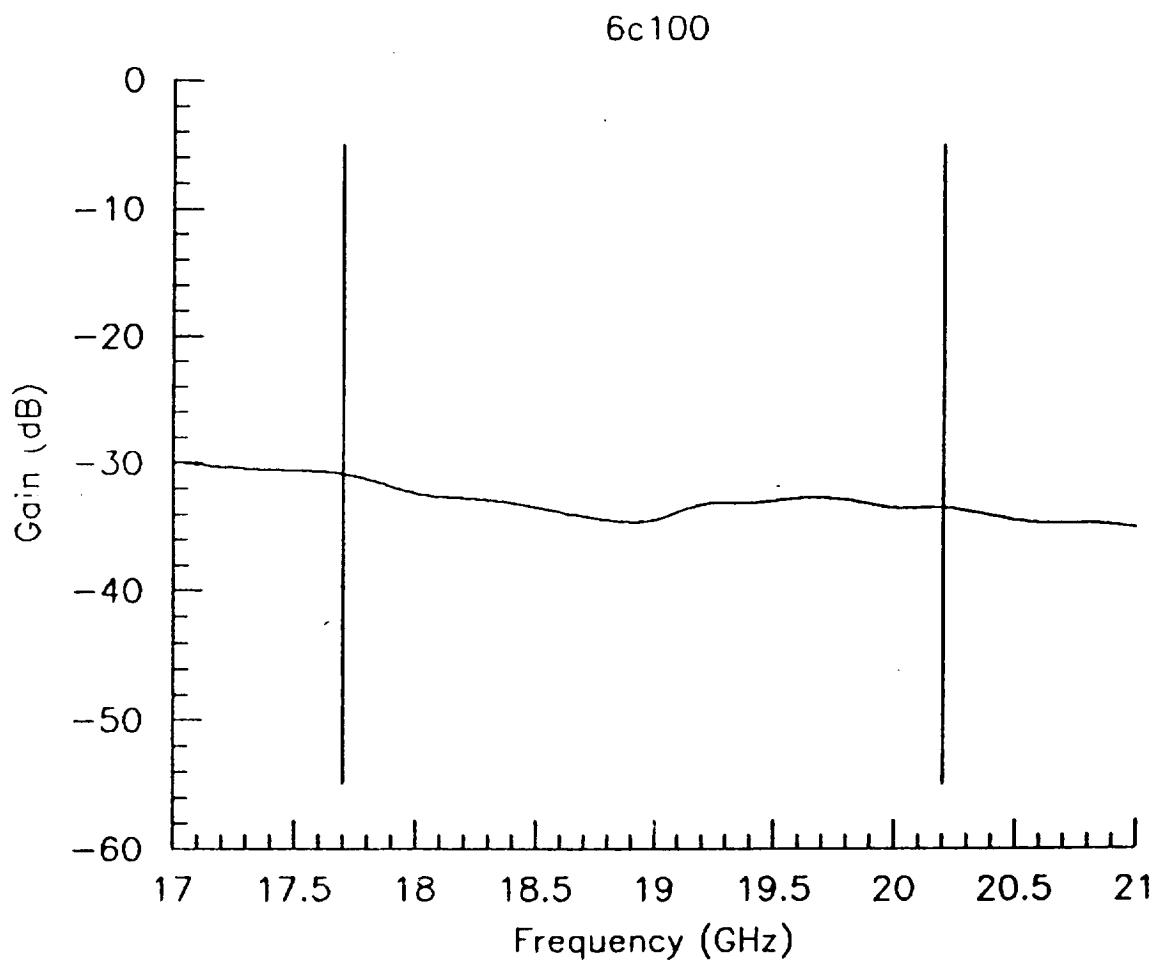


Figure 5.3-2c) Measured Isolation of a Selected Path Through the Packaged 3 X 3 Monolithic GaAs RF Switch Matrix without Buffer Amplifiers



**Figure 5.3-2d) Measured Isolation of a Selected Path Through the Packaged
3 X 3 Monolithic GaAs RF Switch Matrix without
Buffer Amplifiers**

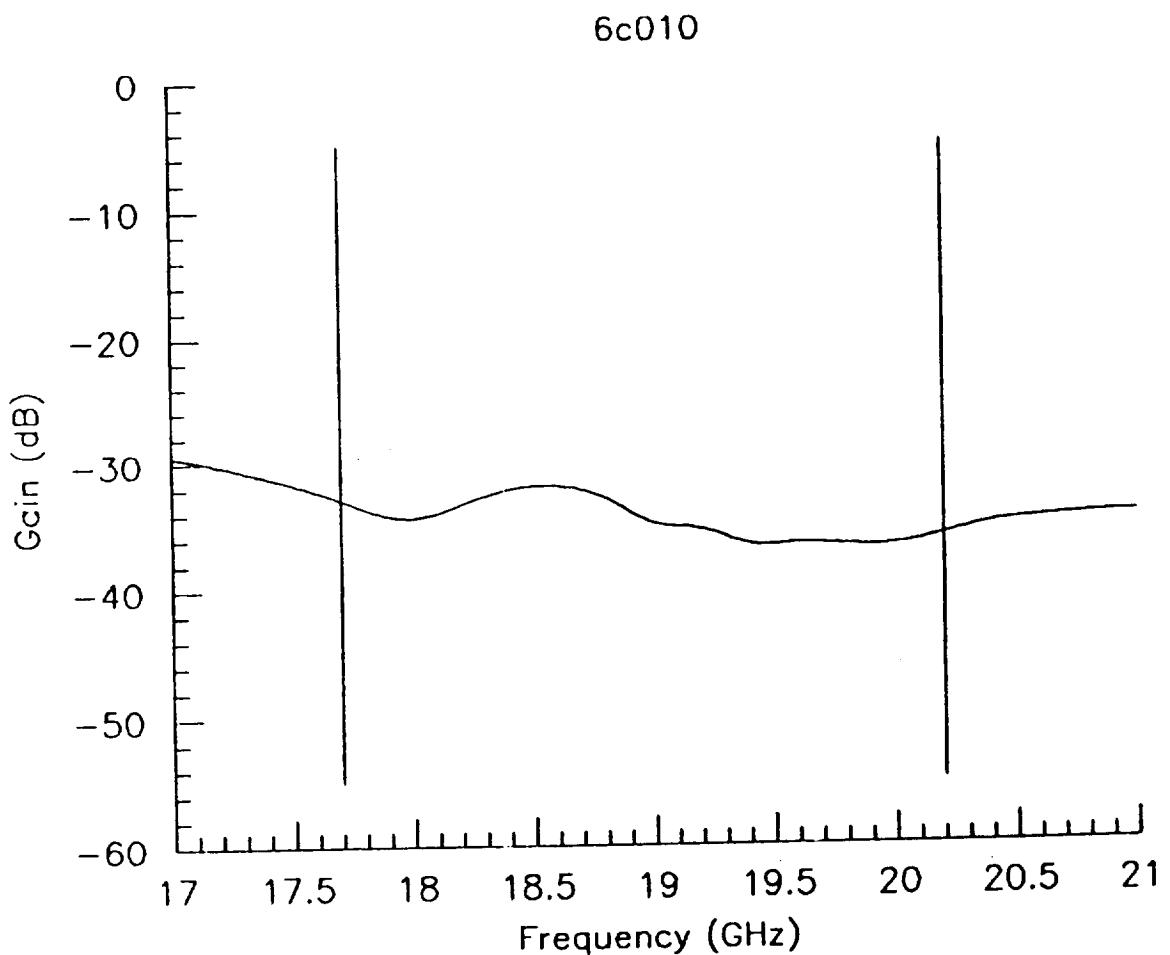


Figure 5.3-2e) Measured Isolation of a Selected Path Through the Packaged
3 X 3 Monolithic GaAs RF Switch Matrix without
Buffer Amplifiers

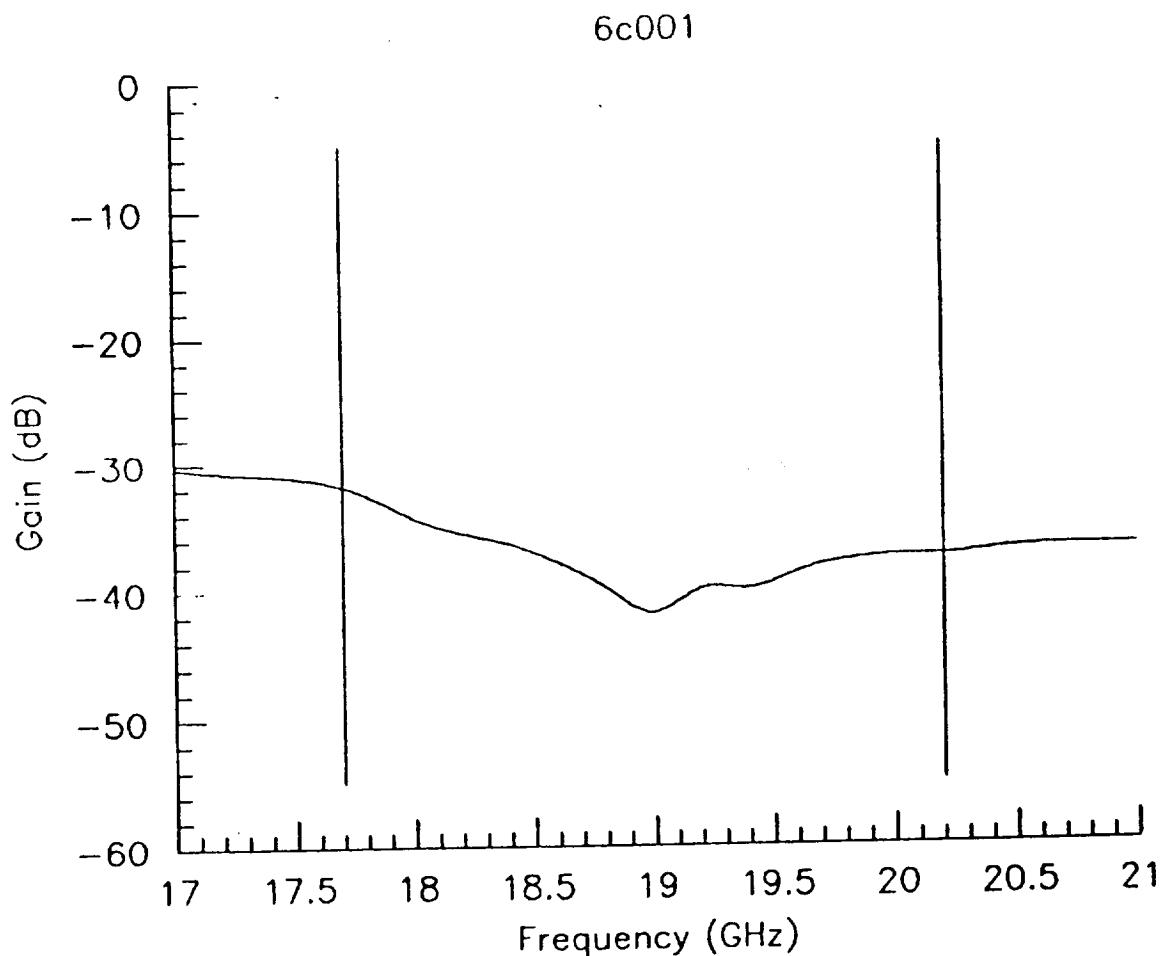


Figure 5.3-2f) Measured Isolation of a Selected Path Through the Packaged
3 X 3 Monolithic GaAs RF Switch Matrix without
Buffer Amplifiers

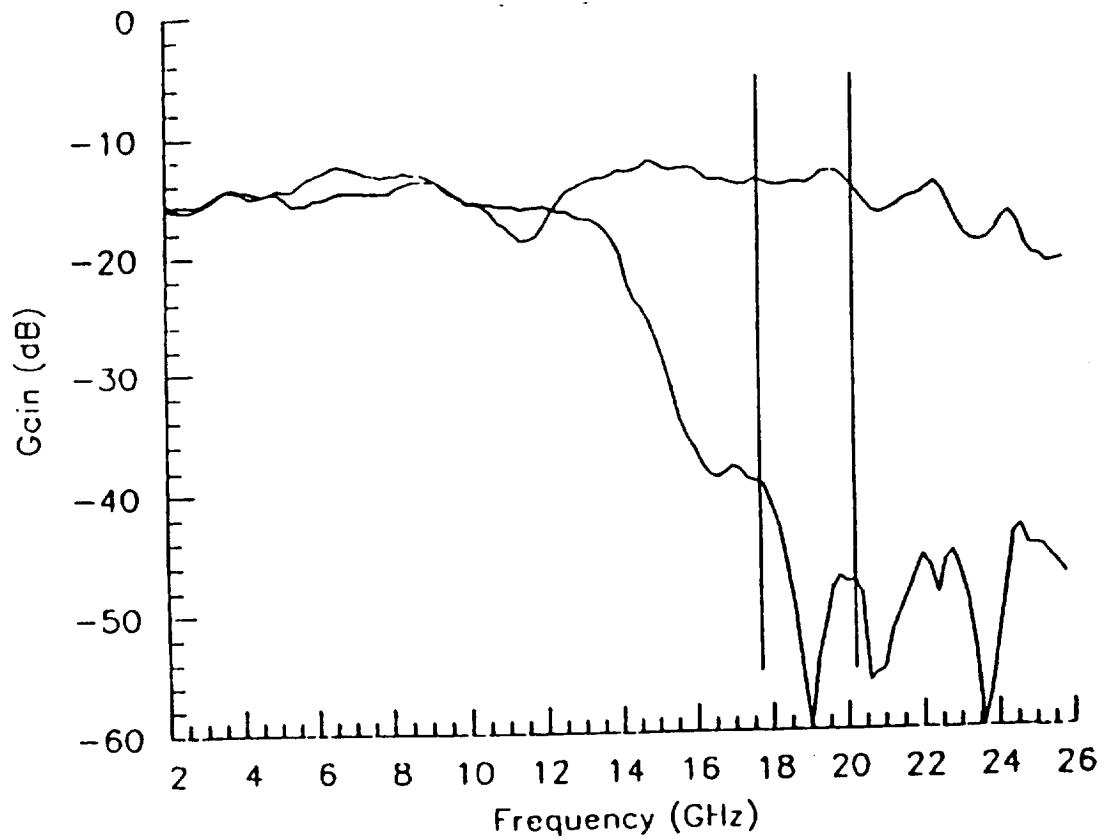
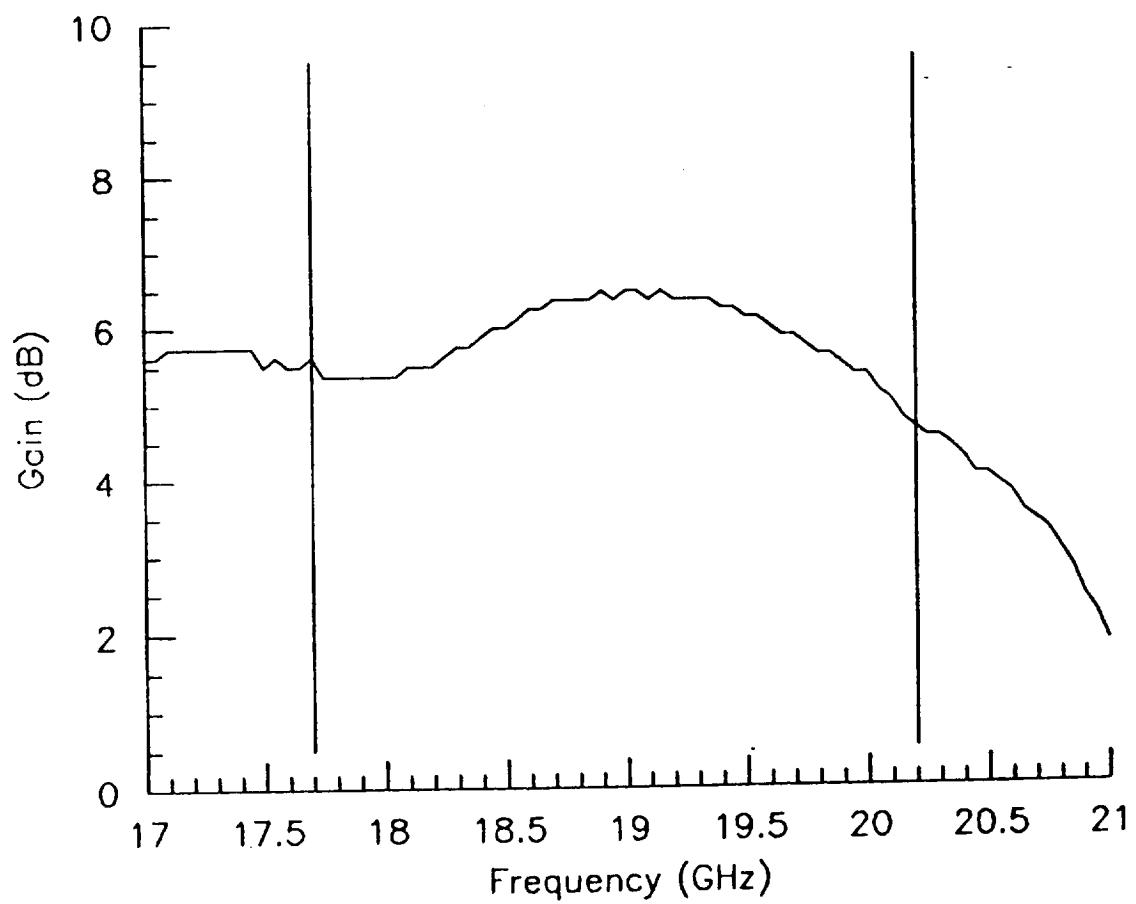
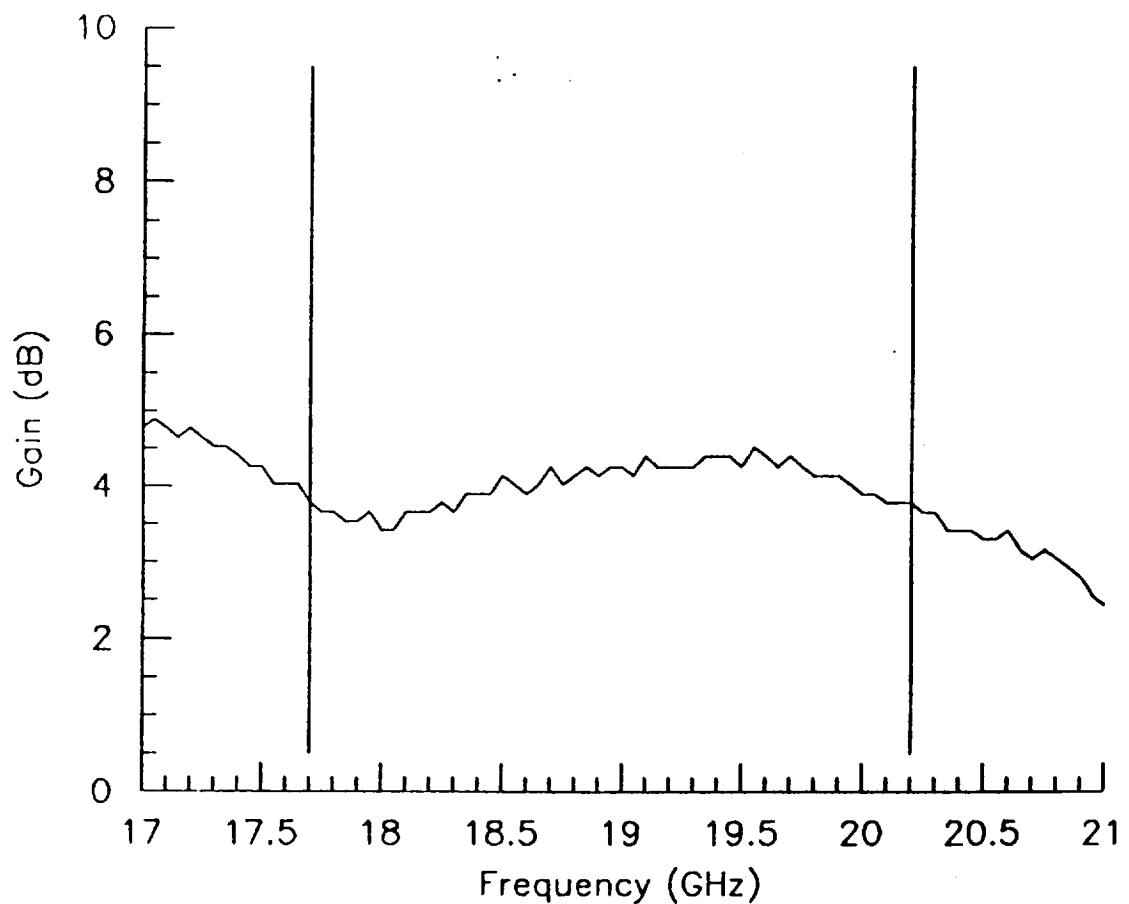


Figure 5.3-3) Measured Wideband Performance of the Packaged RF Switch Matrix Without Buffer Amplifiers



5.4-1a) Typical Measured Buffer Amplifier Performance



5.4-1b) Typical Measured Buffer Amplifier Performance

Table 5.3-1)

DATA FORMAT CODES

CODE = [P1] [P2] [X] [Y] [Z]

P1 = RF INPUT PORT NUMBER

P2 = RF OUTPUT PORT NUMBER

X = SWITCH STATES FOR ROW 1

Y = SWITCH STATES FOR ROW 2

Z = SWITCH STATES FOR ROW 3

STATE = 4 FOR COLUMN 1 SWITCHED ON

STATE = 2 FOR COLUMN 2 SWITCHED ON

STATE = 1 FOR COLUMN 3 SWITCHED ON

STATE = 0 FOR NO COLUMNS SWITCHED ON

Total power consumption, critical for spaceborne applications, is nearly negligible for the 3 X 3 switch matrix without buffer amplifiers. Leakage current in the "off" state for each FET switch (supply voltage = -4.5 volts) is at most 10 microamps, while forward current is approximately the same for properly adjusted bias voltages (approximately +0.7 volts). Therefore only 3.7 milliwatts is required for operation of the full 3 X 3 switch matrix, with only slight increases occurring for high speed TDMA operation. This scales to just 42 milliwatts for a 10 X 10 matrix and 4.2 watts for a full 100 X 100 array. Naturally the buffer amplifiers and control logic would add to this total.

Due to the extensive effort required to fabricate and package the full 3 X 3 monolithic RF switch matrix, the high risk associated with integration of the buffer amplifiers (which had never been done before), technical direction from NASA indicated that further integration should not be attempted until a second fully functional unit became available. That did not occur within program constraints, therefore the fully functional 3 X 3 switch matrix was delivered to NASA Lewis Research Center without integral buffer amplifiers. Measured performance of this switch matrix is presented in Appendix A. Instead, the buffer amplifiers were individually packaged for external connection to the packaged switch matrix via SMA connectors.

5.4) Buffer Amplifier Performance

As previously described, both one and two stage buffer amplifiers were developed under this program to compensate for the insertion loss of the passive RF switch matrix. Typical measured gain for these buffer amplifiers are shown in Figure 5.4-1. Some of these amplifiers were placed in individual housings, with the gain of each was adjusted, to the extent possible, on a case by case basis to compensate the insertion loss of the particular 3 X 3 switch matrix delivered to NASA and described in Appendix A. Measured gain for each of the six packaged buffer amplifiers delivered to NASA are presented in Appendix A.

5.5) Projected Performance of Integrated Subsystem

Program constraints did not permit full characterization of the 3 X 3 RF switch matrix with integrated buffer amplifiers, however the measured gain of each delivered buffer amplifier was added (for each measurement frequency across the band) to the gain and insertion loss measured for the delivered 3 X 3 RF switch matrix. A complete set of this merged data is presented in Appendix A.

5.6) NASA Switch Matrix Control Box

The control box supplied by NASA is capable of full TDMA operation, and has sufficient memory for 1024 time slices. Positive and inverted output signals are available for each crosspoint (up to 10 X 10 crosspoints), with the magnitude of each voltage adjustable between 0 and 10 volts. Normal operating voltages are +0.7 volts and -4.5 volts, with +1.0 and -5.0 also commonly utilized. The matrix can be held in one static state or cycled through the TDMA memory at dwell times from more than one second down to one microsecond. A standard RS-232 serial computer interface is provided to load the TDMA memory and to control the box, and LED displays provide both matrix state information and current time slot.

Although the monolithic RF switch matrix is a blocking matrix, the control box is capable of broadcast mode operation where a single output would be routed to several outputs. These matrix settings are, none the less, valid for the RF switch matrix but have a different meaning. They can be used to partially evaluate redundant routes through the matrix. Complete evaluation of all redundant paths is not, however, possible since the control box is not capable of routing several inputs to a single output port.

The complete command set for the control box is provided in Appendix C.

6) 10 X 10 MONOLITHIC GaAs SWITCH MATRIX DESIGN

6.1) Circuit Design and Layout

Design of the 10 X 10 Monolithic GaAs RF switch matrix was simplified considerably by the design constraints originally imposed on the 3 X 3 RF switch matrix. In particular, the crosspoint design presented in section 3.2 was intentionally oversized, leaving sufficient room for routing all 10 DC control lines on the 10 X 10 matrix. Therefore, design and digitization of the 10 X 10 switch matrix consists of arraying 100 of these crosspoints and re-routing the control lines to the periphery of the chip. The major obstacle to be overcome is the placement of the 40 RF lines and 200 control lines such that all can be bonded to corresponding traces on the package. This can be accomplished in a 14 X 14 millimeter chip, although the bonding and assembly would be quite complex. Note that this chip size strains the capabilities of most mask tool set manufacturers, however MMInc. has been assured that techniques are available for this specific case.

6.2) Large Matrix Analysis Techniques

Full analysis of a large RF switch matrix easily exceeds the capacity of most microwave circuit simulation computer programs, and strains the largest computer budgets even when programs are enlarged to fill the need. The magnitude of the problem is easily appreciated by considering a 10 X 10 matrix, which contains 20 input ports, 20 output ports, and 121 nodes, not to mention the many internal nodes of each crosspoint and the switching FET models. Repeated inversion of matrices with nearly 15,000 elements is needed for traditional nodal analysis, while standard cascading operations are not suited to the two dimensional structure used in the switch matrix. A full 100 X 100 switch matrix analysis is 100 times more complex, with as many as 1.5 million matrix entries. Furthermore, sparse matrix techniques are not as useful as in more traditional circuit structures since low level leakage paths result in rather full matrices.

It is tempting to do a crude analysis by simply analyzing one crosspoint element and then extrapolating to 10 X 10 (or larger) arrays, however such an approach is overly simplistic and prone to error when very low levels of interaction are significant. Detailed analysis of line ringing due to imperfect VSWR is almost impossible to include within that approach.

However, efficient analysis of large arrays of circuits is possible using a Transfer matrix circuit description approach (as opposed to the more common Scattering, Impedance, or Admittance matrix descriptions). This matrix is similar to the ABCD parameters often used in the analysis of cascaded two ports, except that it is based on traveling power waves (as are S - Parameters) rather than on voltages and currents. A description of the properties of transfer matrices is given in Reference 3. Straight forward generalization of this matrix description leads to efficient analysis of two dimensional cascaded circuit arrangements. Using this technique, once the modified Transfer matrix for each 4 port crosspoint element (both "on" and "off") is generated (an easy task starting from the S - Parameters generated by standard

linear analysis), the larger matrix can be generated using only repeated matrix addition and multiplication. While this can still consume substantial computer time for large arrays, it represents a significant saving of computer resources.

By this analysis technique, the Transfer matrix of an entire monolithic array (or complete RF switch matrix) is generated with no large matrix inversions. Inversion of one quarter of the final large matrix for each configuration of switch settings (at each frequency analyzed) is required to produce a Scattering matrix of the array, however that is substantially less work than inversion of the entire matrix. Furthermore, the transfer matrix itself has most of the desired information (including all insertion loss and isolation data), thereby often eliminating the need for the inversion of large matrices. This is the rational for using the transfer matrix rather than the ABCD matrix, generalizations of which would also work without necessity of matrix inversion. Although not required in the present application, it is interesting to note that extension to three or more dimensions of iteration is also possible using this approach. Many efficiency enhancements are possible, and are advisable for analysis of 100 by 100 or larger arrays.

The previously described predicted performance for the 3 X 3 matrix was generated with the aid of these techniques, as are the 10 X 10 results presented next. A two by two array was also analyzed by both traditional circuit analysis techniques and the Transfer matrix approach to verify that they produced the same results. Larger arrays could not be analyzed by available standard programs for further verification without modifications, which were not performed since the results agreed for the 2 X 2 array.

6.3) Preliminary Performance Estimates

Performance estimates for the 10 X 10 GaAs monolithic RF switch matrix were generated with the aid of MONO and the software described in section 6.2. The 40 X 40 scattering matrix generated at each frequency for each matrix control setting contains 1600 complex numbers. In the unlikely event that sufficient computer resources were committed to the task, a full analysis of the 2^{100} possible states would have resulted in an excessively large final report. Therefore three selected representative states (the same ones presented in section 3.3 for the 3 X 3 switch matrix) were analyzed in full. The detailed results of this analysis are presented in Appendix B, including the effect of the fixed gain buffer amplifiers around the periphery of the matrix.

7: CONCLUSION AND RECOMMENDATIONS

As demonstrated by the results presented in this report, the performance of MMInc.'s packaged monolithic GaAs 20 GHz RF switch matrix is very impressive. Measured package isolation is better than the required 60 dB, and insertion loss is well within the compensation range of the buffer amplifiers. A fully functional 3 X 3 monolithic GaAs 20 GHz RF switch matrix with all required external buffer amplifiers was delivered to NASA Lewis Research Center at the conclusion of this program. In summary, proof of concept (POC) for the 20 GHz RF monolithic switch matrix has been established.

There remain, however, several crucial issues which must be resolved prior to practical application of this advanced technology. Some of these issues, such as yield improvement and integral control electronics, can benefit from other MMIC development activities, however some are unique to the monolithic 20 GHz RF switch matrix. In particular, additional effort is required to further optimize the package/chip interface to maintain the high isolation inherent in the package and chip designs, and to further refine the resonant crosspoints to minimize undesired parasitic interactions. It is therefore recommended that a 10 X 10 (or TBD) monolithic GaAs 20 GHz RF switch matrix be designed, fabricated, characterized, and evaluated with the following objectives: A) Optimize circuit design and layout for high performance and user acceptability, including an optimized control interface, B) Optimize the package/MMIC chip interface and incorporate hermetic space qualifiable package design and fabrication for high performance spaceborne applications, C) Application of yield enhancement techniques at all stages of the fabrication and testing sequence, and D) Development of efficient assembly and test procedures for monolithic switch submatrix and matrix integration. This large submatrix would be extremely useful in a wide range of practical applications, and would provide a realistic assessment of large matrix performance in breadboard advanced communications systems spearheaded by the NASA Lewis Research Center.

With full implementation of the technology base developed by MMInc., ground, air, or spaceborne operational switch matrix subsystems of arbitrary size, possibly extending to 100 X 100 crosspoints or more, could be developed at reasonable cost and confidence level. Switching at the RF frequencies as opposed to IF frequencies could significantly reduce the complexity of advanced space based communications satellites, which could prove crucial to their eventual deployment. Without such complexity reducing tactics to partially counteract ever increasing complexity, systems performance goals might have to be relaxed due to overall systems reliability, size, and weight considerations. Thus, this exciting new monolithic GaAs switch matrix technology would allow realization of the advanced communications systems architectures envisioned by NASA as well as many as yet unforeseen systems concepts.

8) REFERENCES

- 1) Ford Aerospace & Communications Corporation, "Spacecraft Switch Matrix and Wideband Service Applications in 30/20 GHz Communications Satellite Systems", Task II Final Report for NASA contract NAS3-22501, November, 1981.
- 2) General Electric Company, "30/20 GHz Satellite Switching Matrix Development", Task II Final Report for NASA contract NAS3-22500, March 1981.
- 3) Carlin and Giordano, NETWORK THEORY: An Introduction to Reciprocal and Nonreciprocal Circuits, Prentice-Hall, pp. 302-325.

9) APPENDIX A: Delivered 3 X 3 RF Switch Matrix

This appendix describes the 3 X 3 RF matrix delivered to NASA Lewis Research Center under this contract.

9.1) Control Ribbon Wire List

Figure 9.1-1 identifies the wiring configuration and required signal levels for the 3 X 3 RF switch matrix delivered to NASA.

	A1	B1	C1	A2	B2	C2	A3	B3	C3	
A1	:		:			:				A1
A2		A1	:	B1		:	C1			A2
A3			:			:				A3
B1										B1
B2		A2	:	B2		:	C2			B2
B3			:			:				B3
C1										C1
C2		A3	:	B3		:	C3			C2
C3			:			:				C3

A1 B1 C1 A2 B2 C2 A3 B3 C3

Crosspoint "0" State: $X = +1.0 \text{ V}$
 $X = -4.5 \text{ V}$

Crosspoint "1" State: $X = -4.5 \text{ V}$
 $X = +1.0 \text{ V}$

Figure 9.1-1) Control Ribbon Wire List

9.2) Measured Matrix Performance

Figures 9.2-1 through 9.2-24 are the measured frequency response between all possible redirected input and output ports and with the intersecting crosspoint both "on" and "off". Note that both the primary and secondary paths inherent in the switching architecture utilized are presented in this section. Each figure caption presents the port numbers for the corresponding plot as defined in section 5.3 of this report.

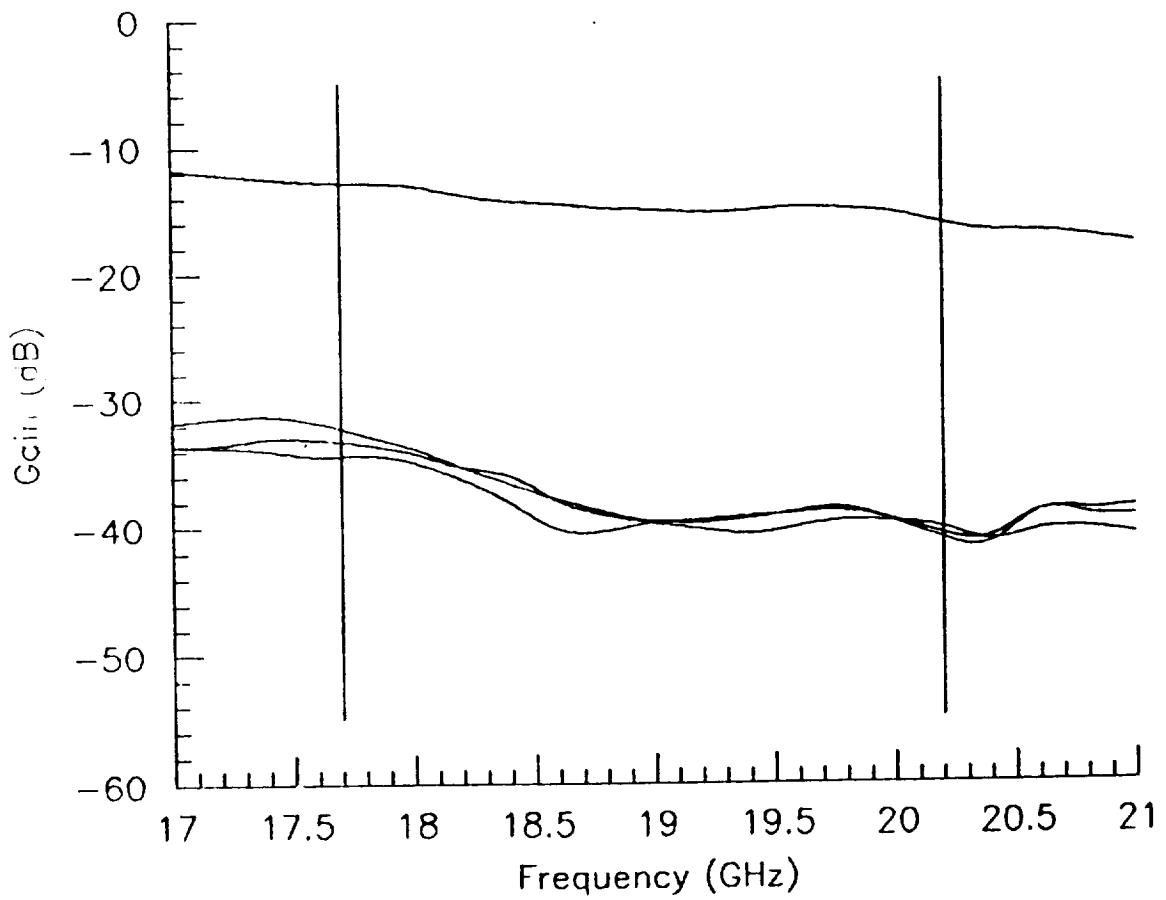


Figure 9.2-1) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

1a

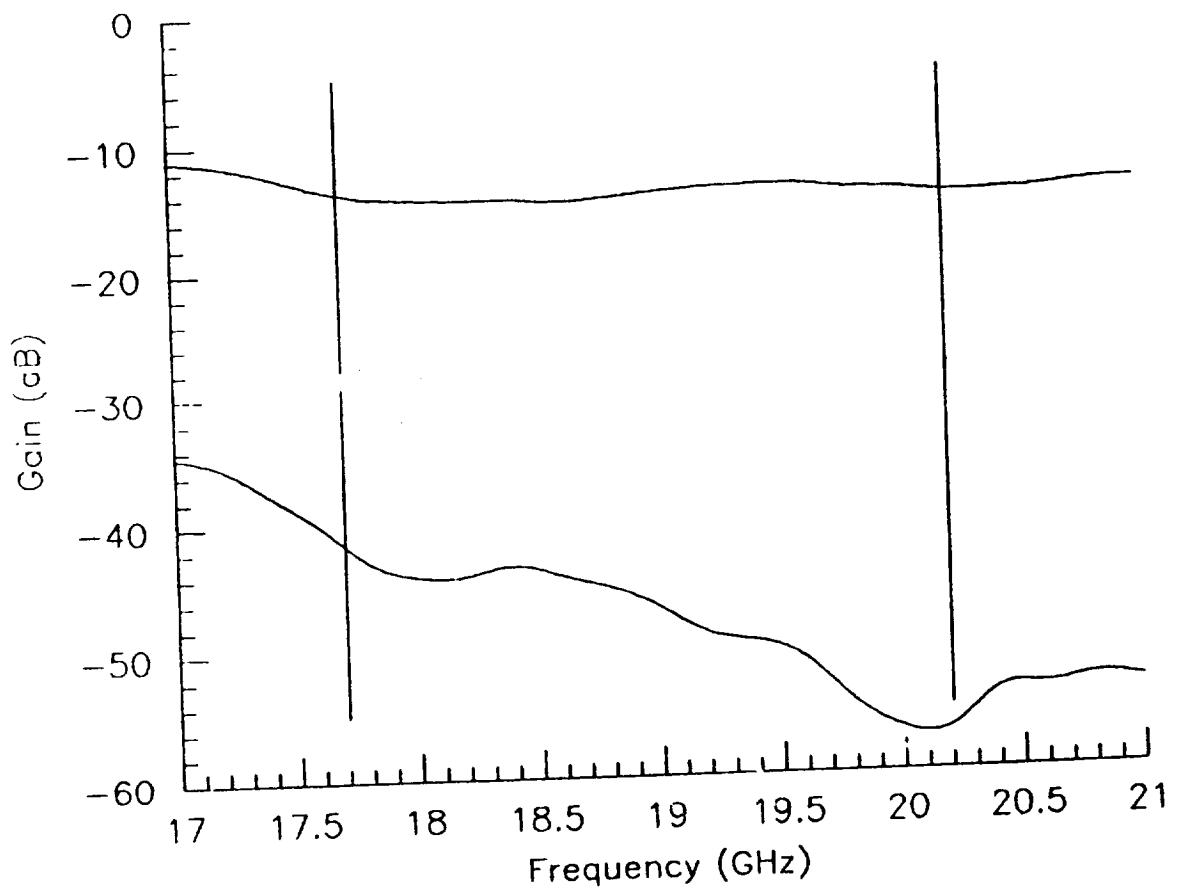


Figure 9.2-2) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

1b

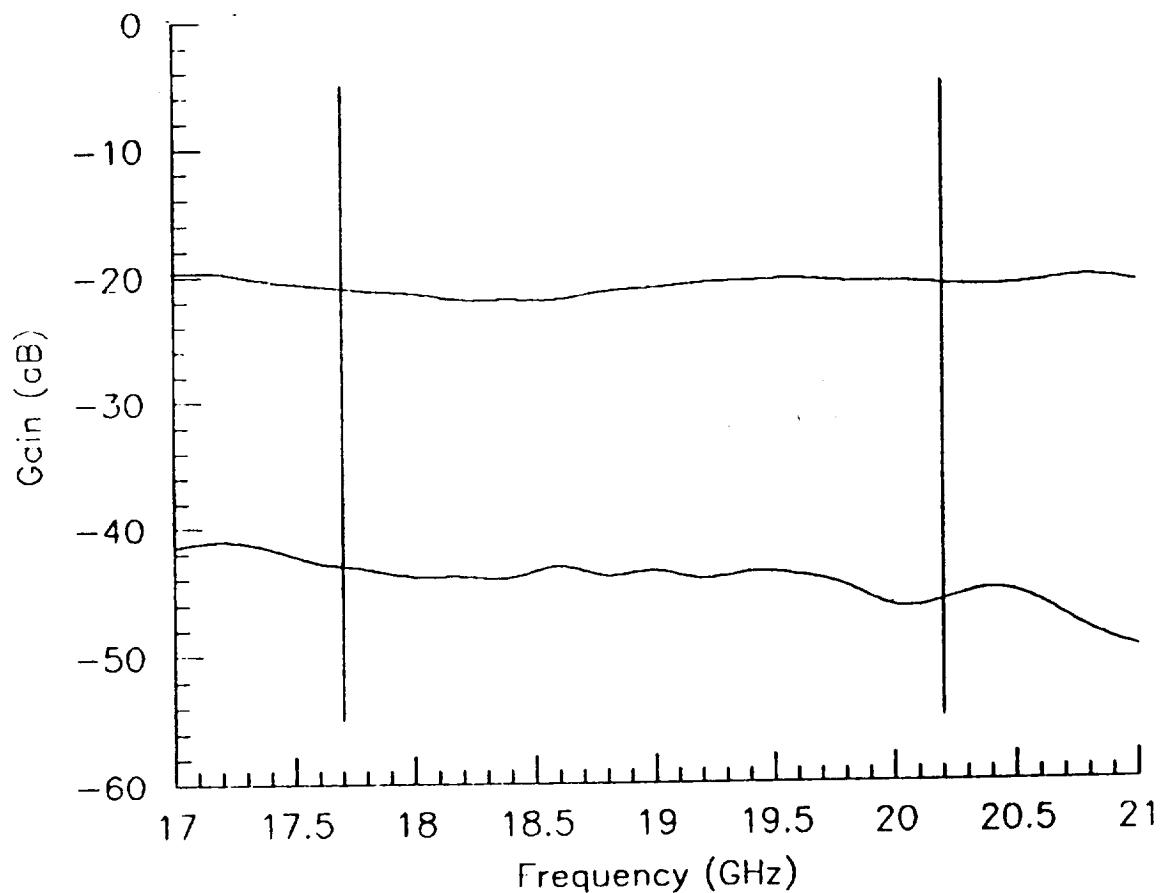


Figure 9.2-3) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

1c

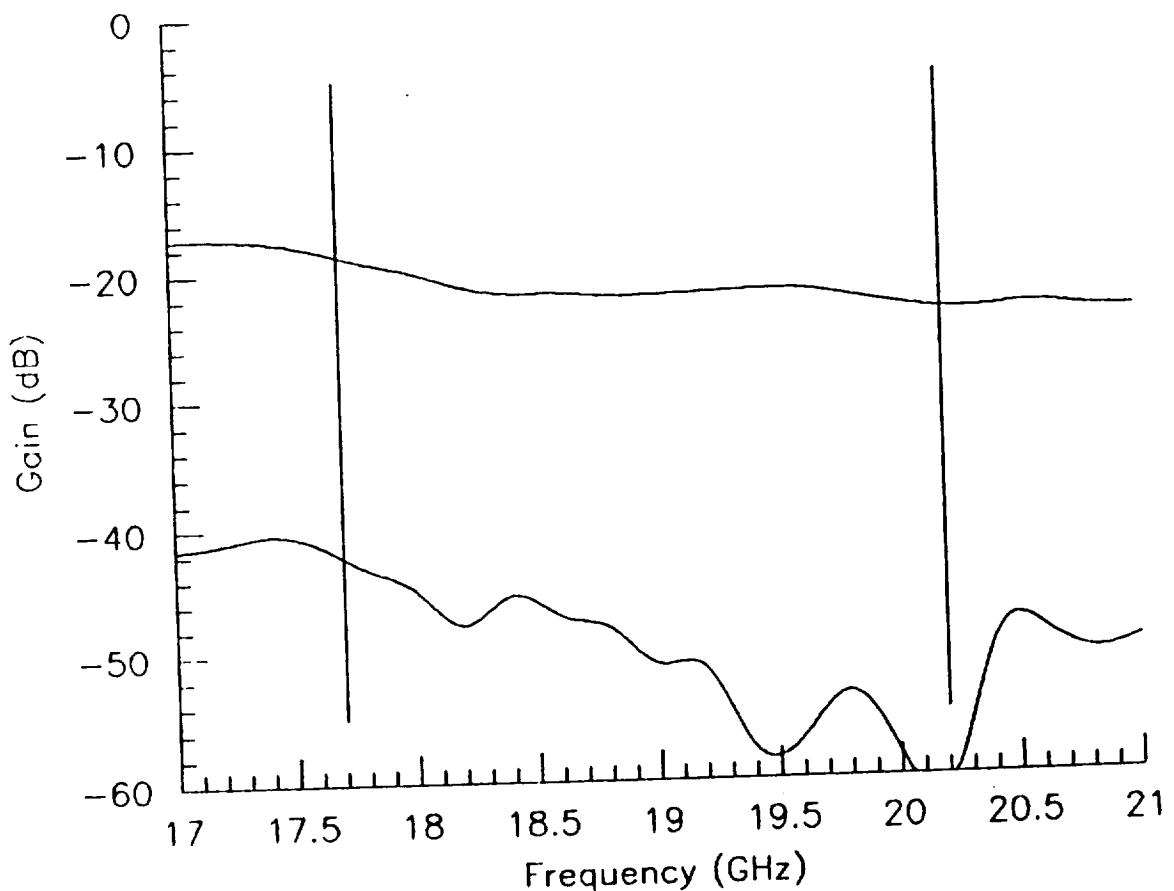


Figure 9.2-4) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

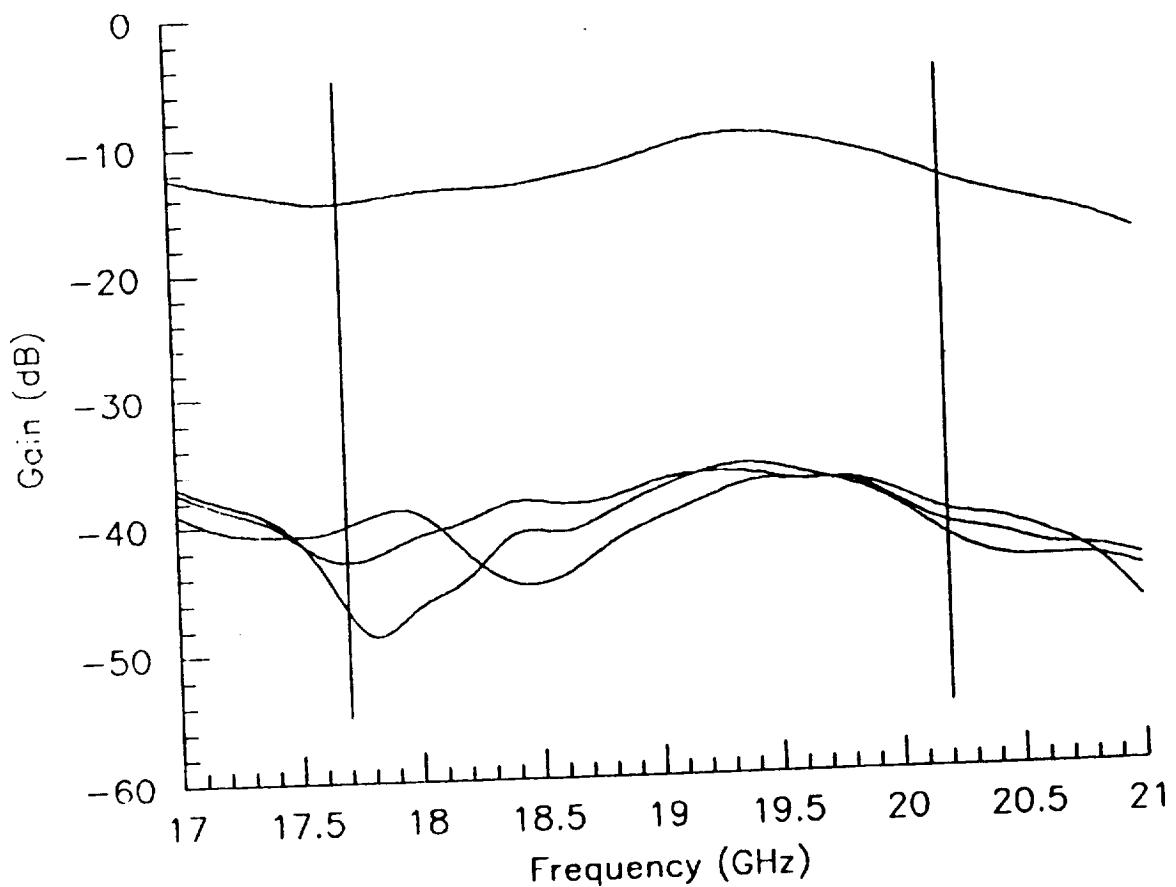


Figure 9.2-5) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

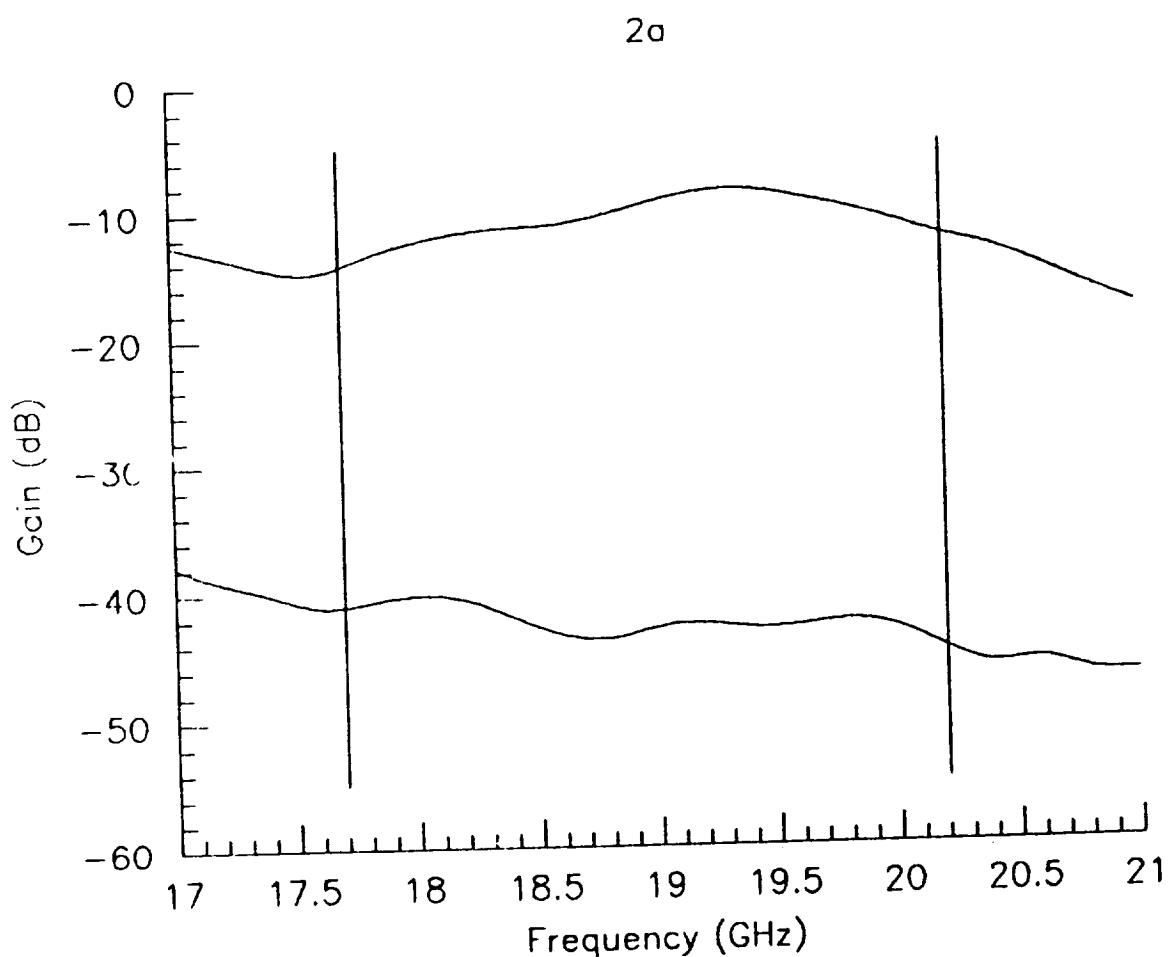


Figure 9.2-6) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

2b

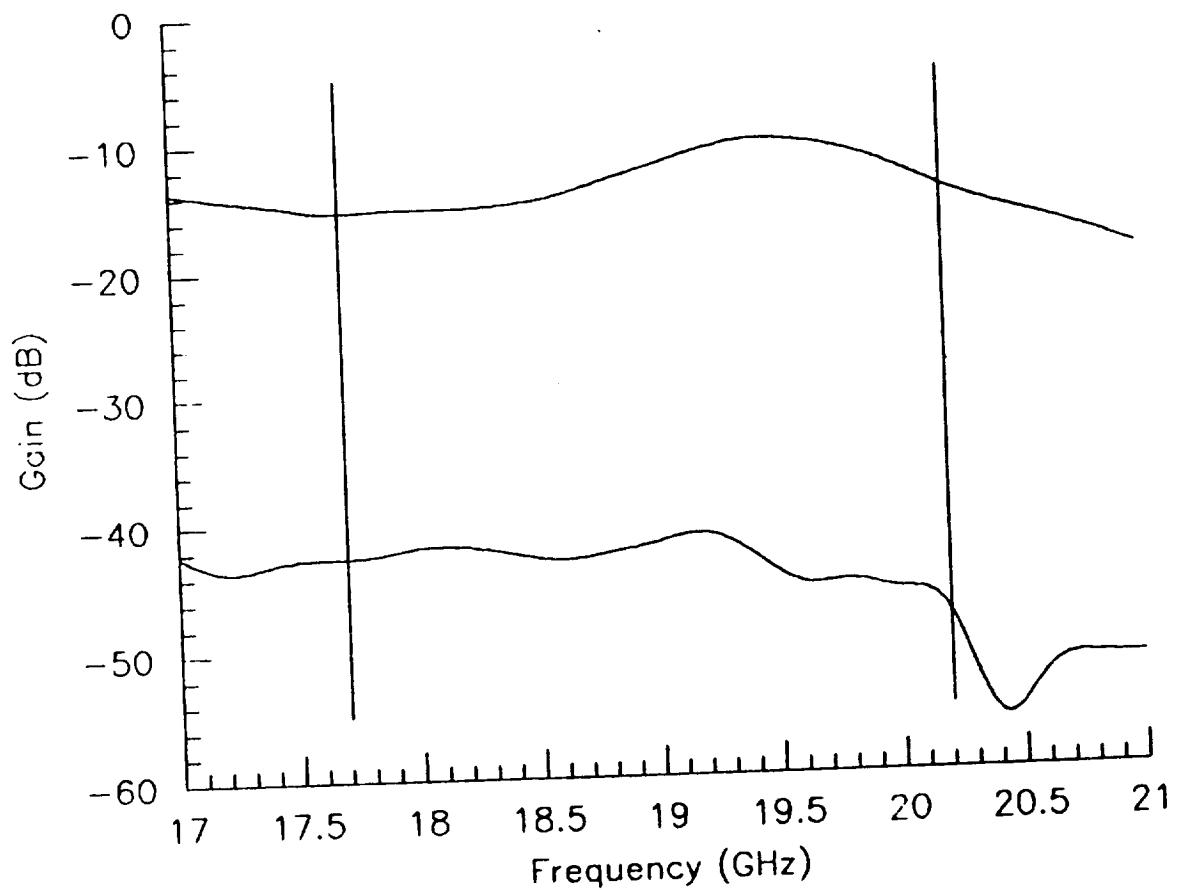


Figure 9.2-7) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

2c

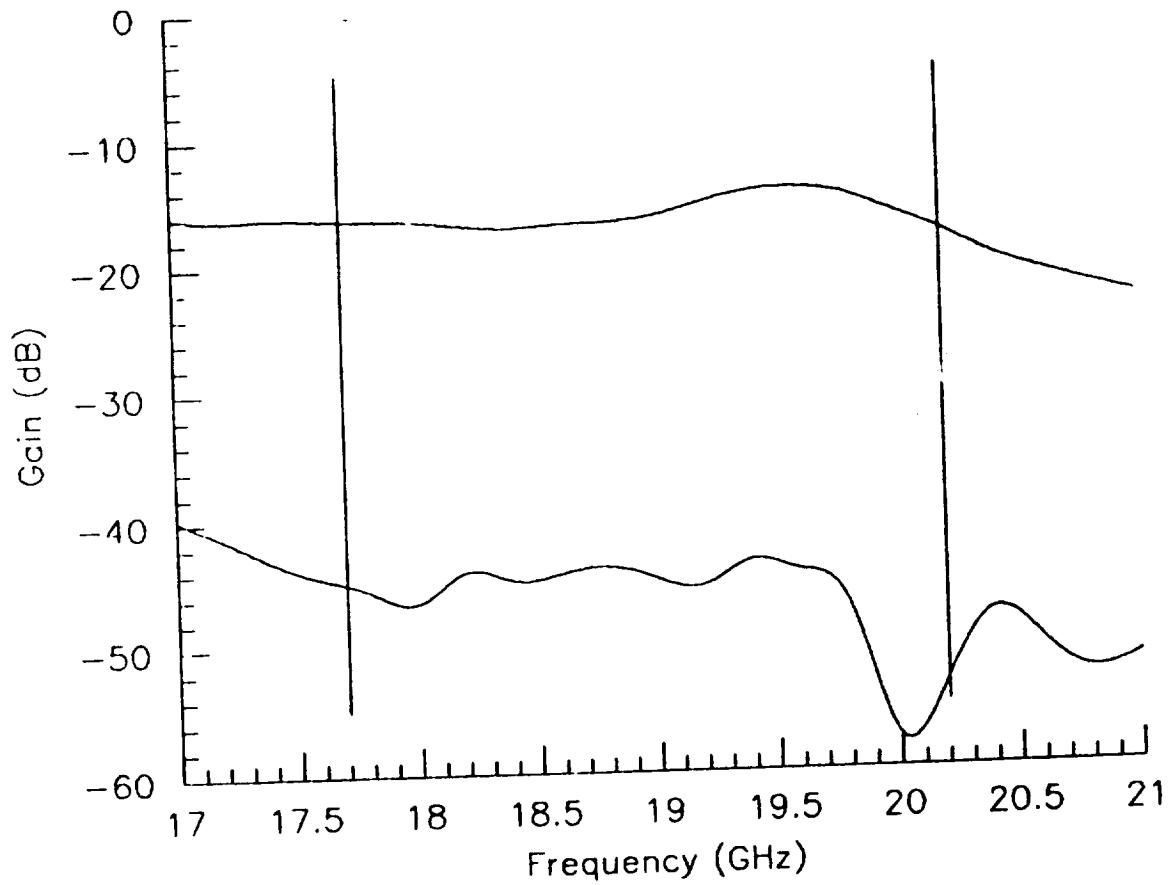


Figure 9.2-8) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

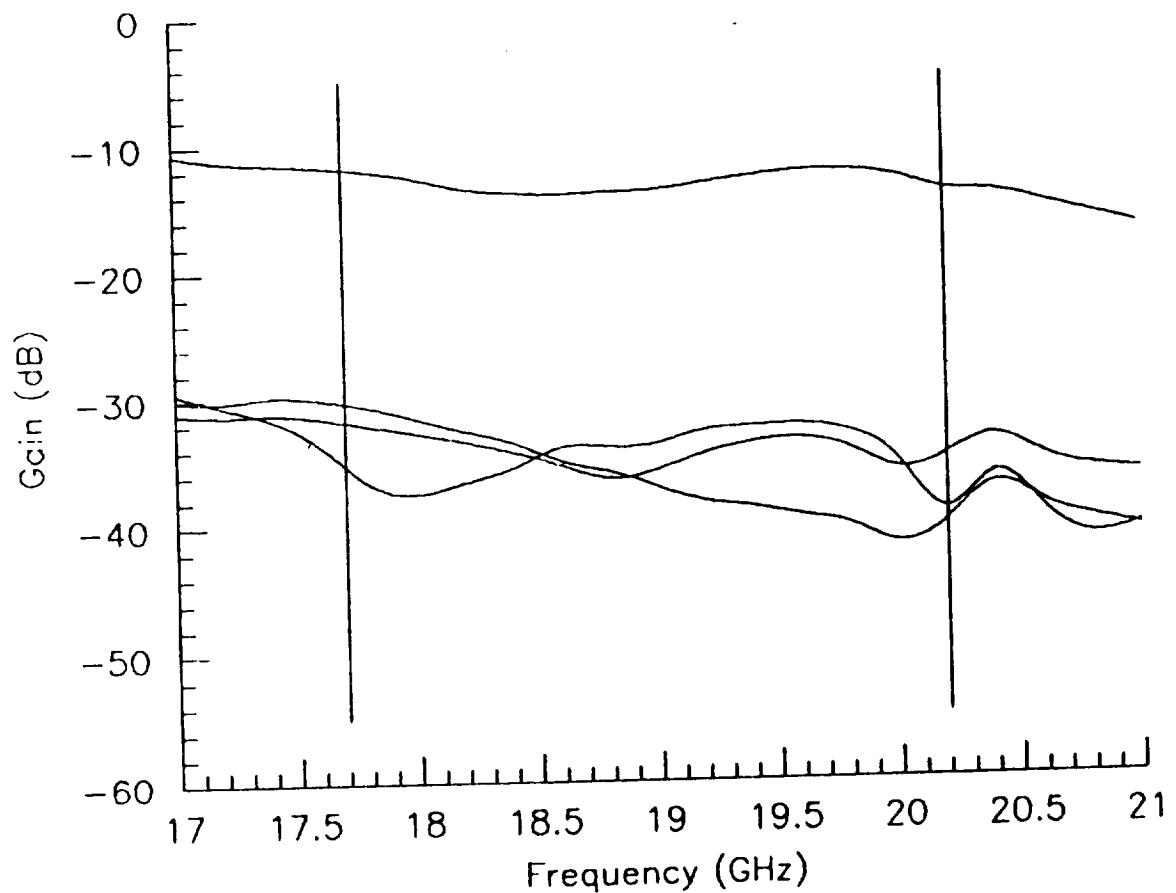


Figure 9.2-9) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

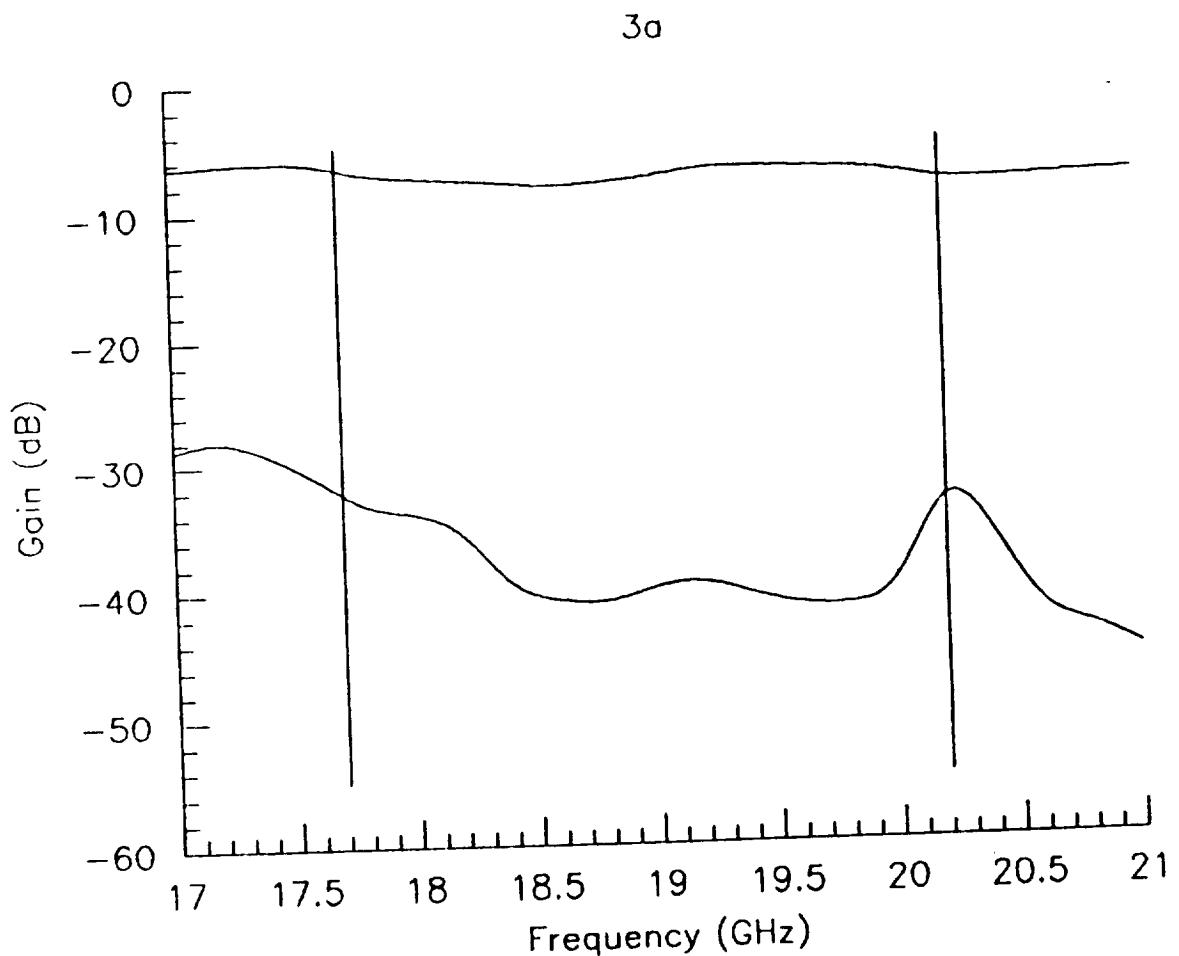


Figure 9.2-10) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

3b

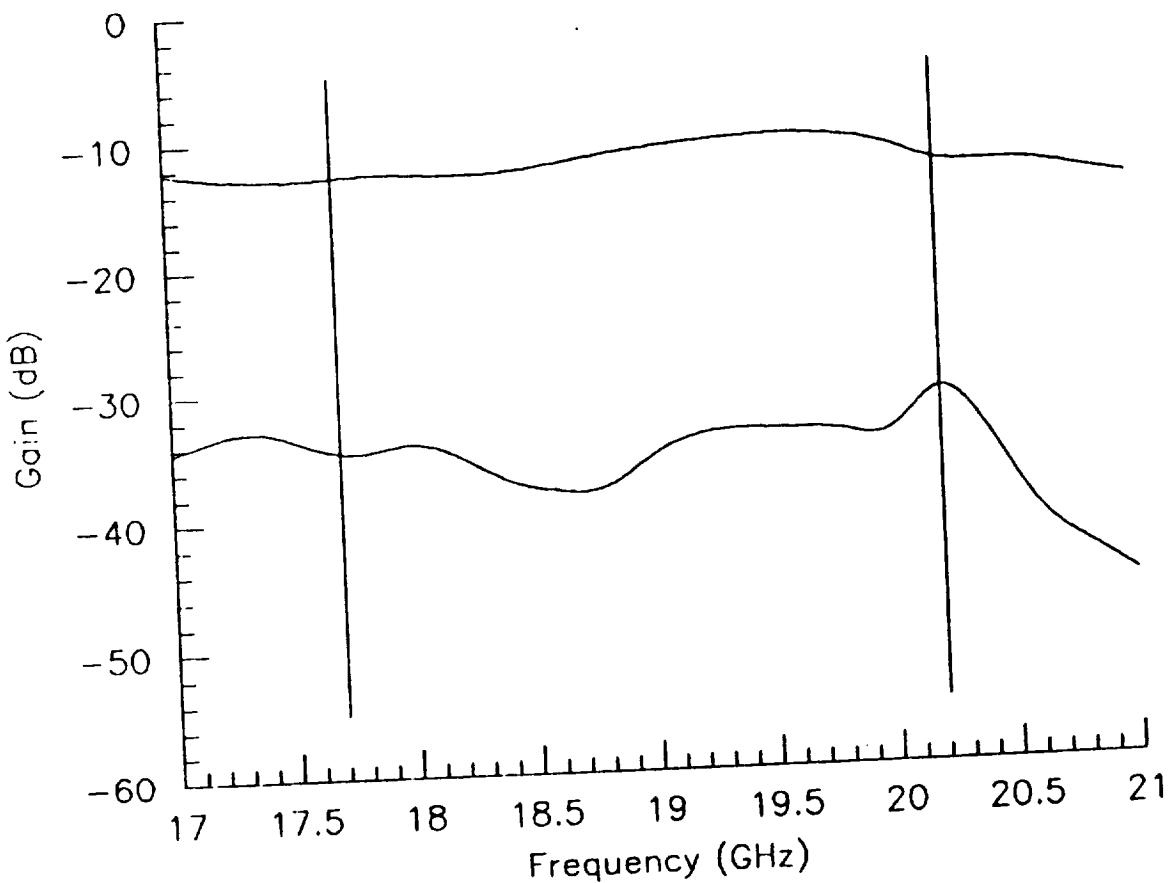


Figure 9.2-11) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

3c

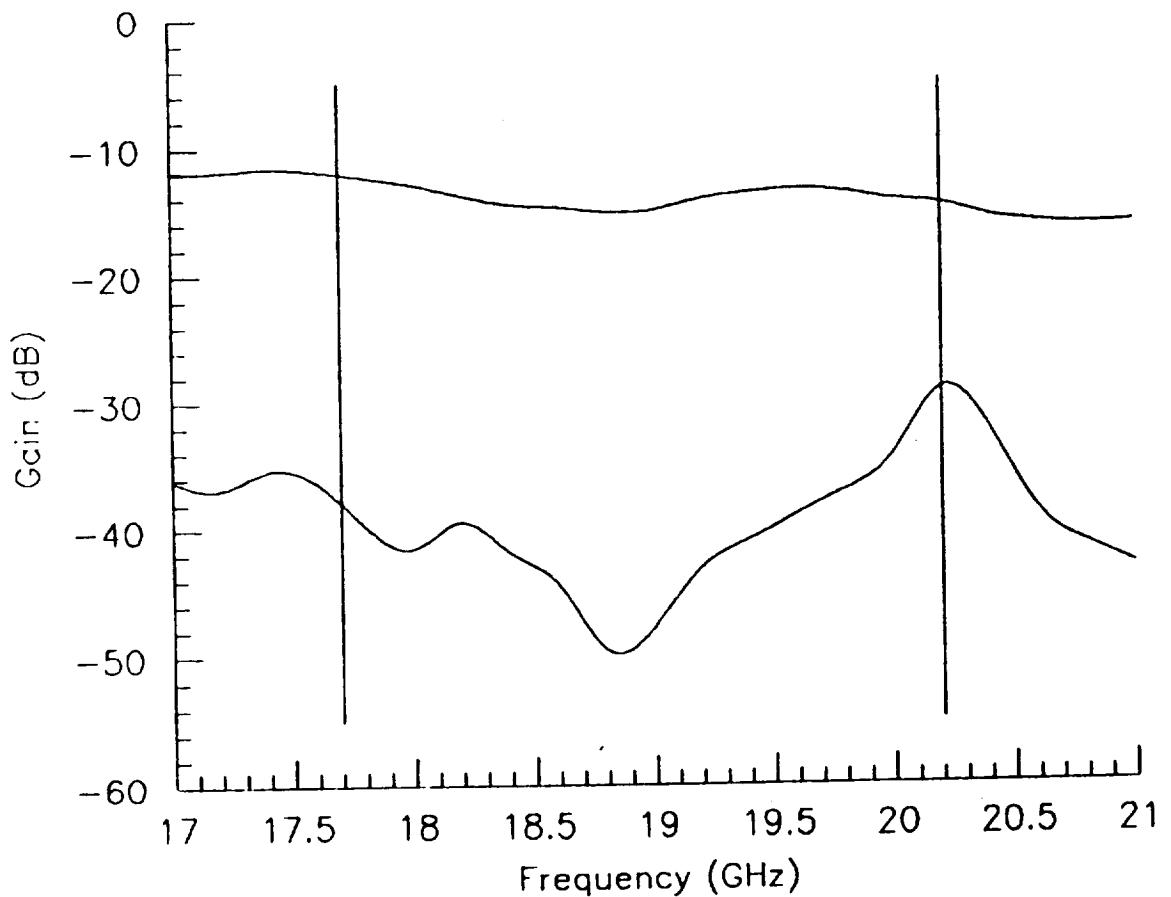


Figure 9.2-12) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

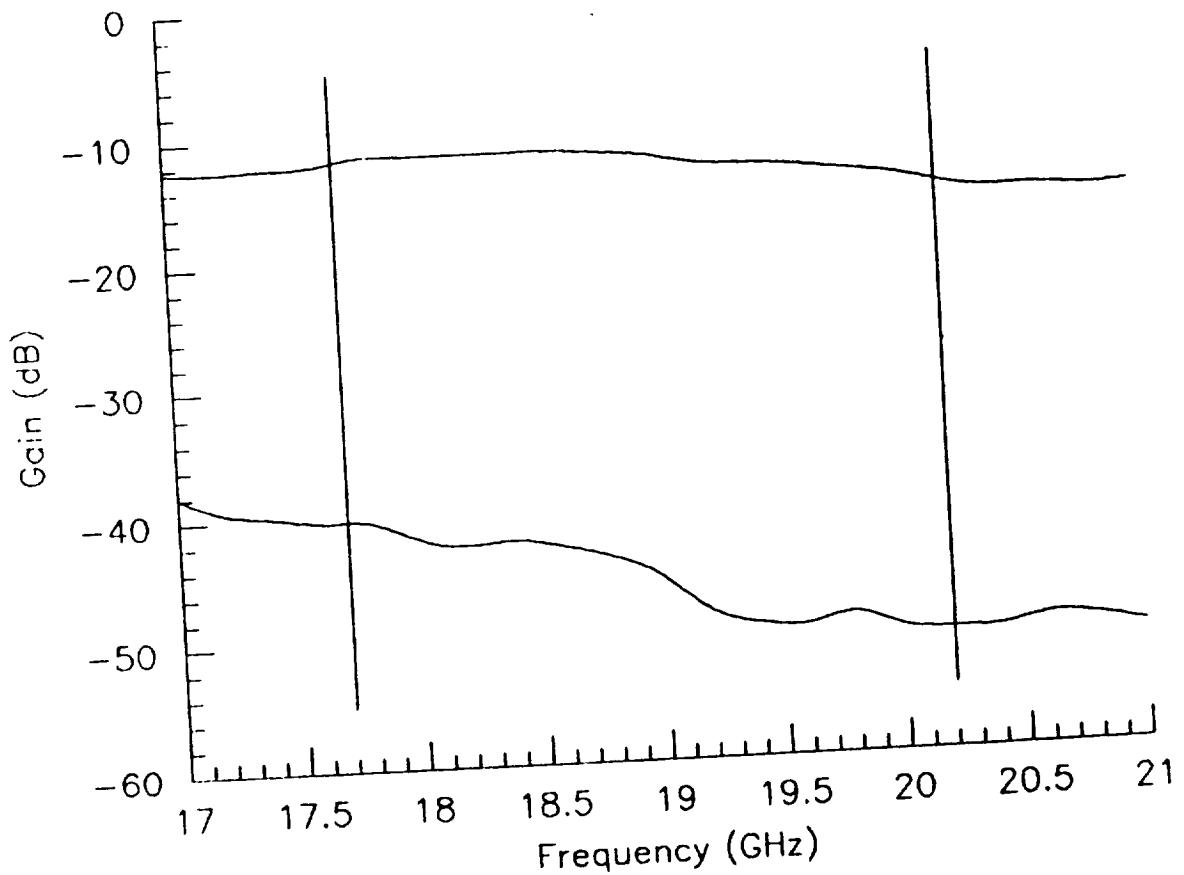


Figure 9.2-13) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

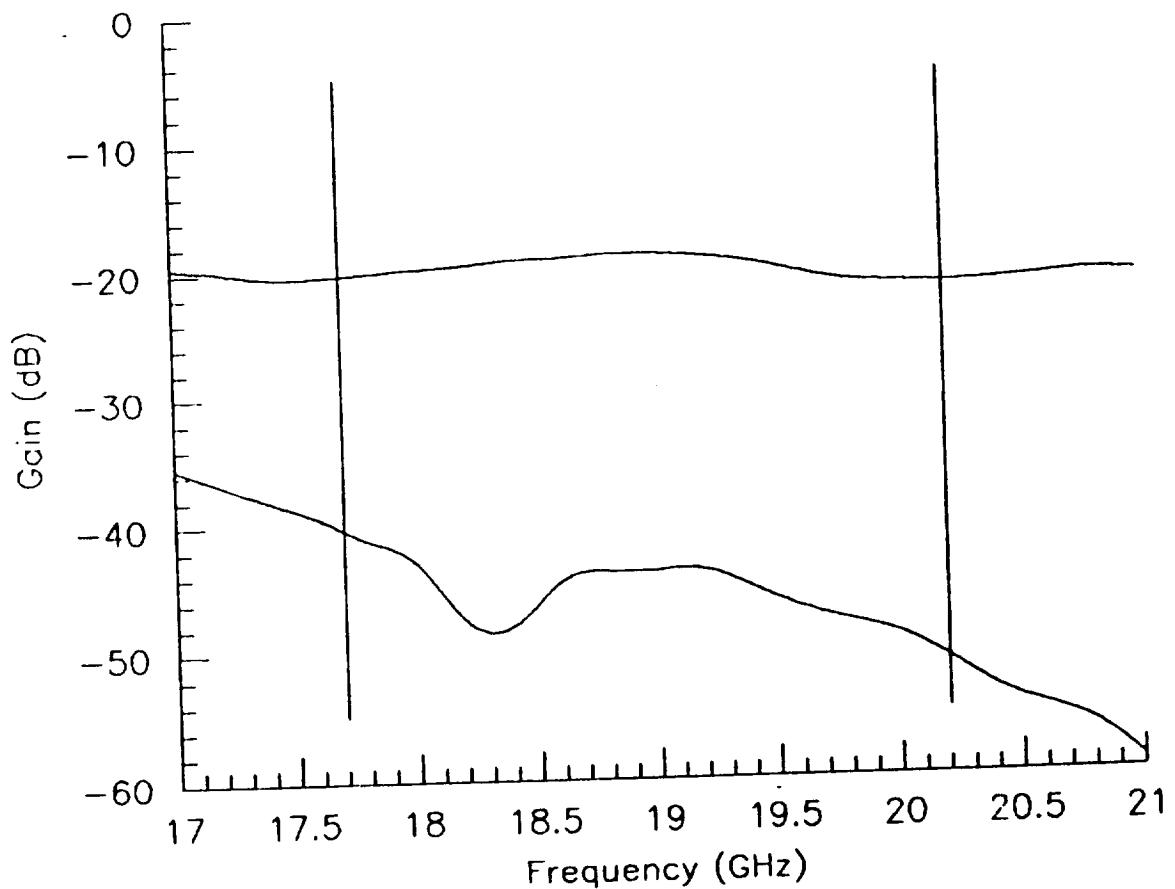


Figure 9.2-14) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

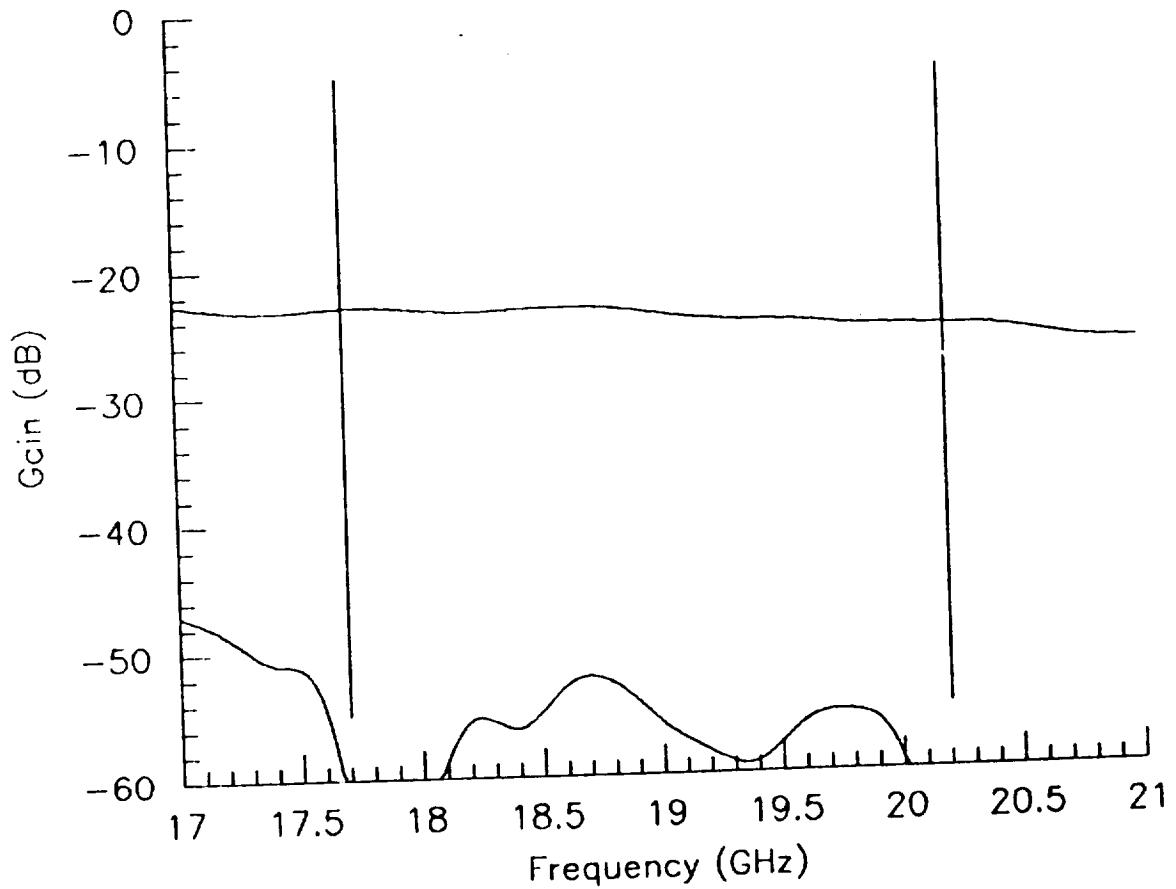


Figure 9.2-15) Measured Performance of the 3×3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

4a

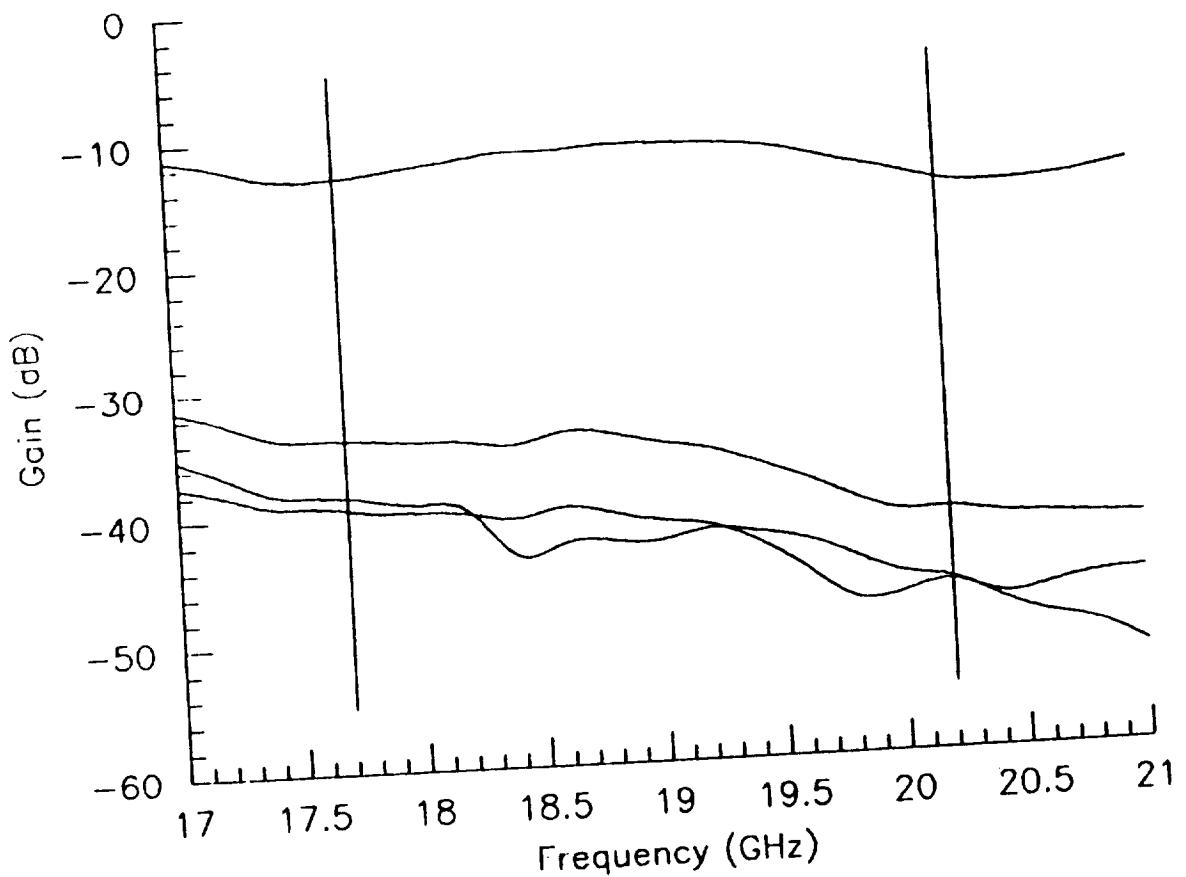


Figure 9.2-16) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

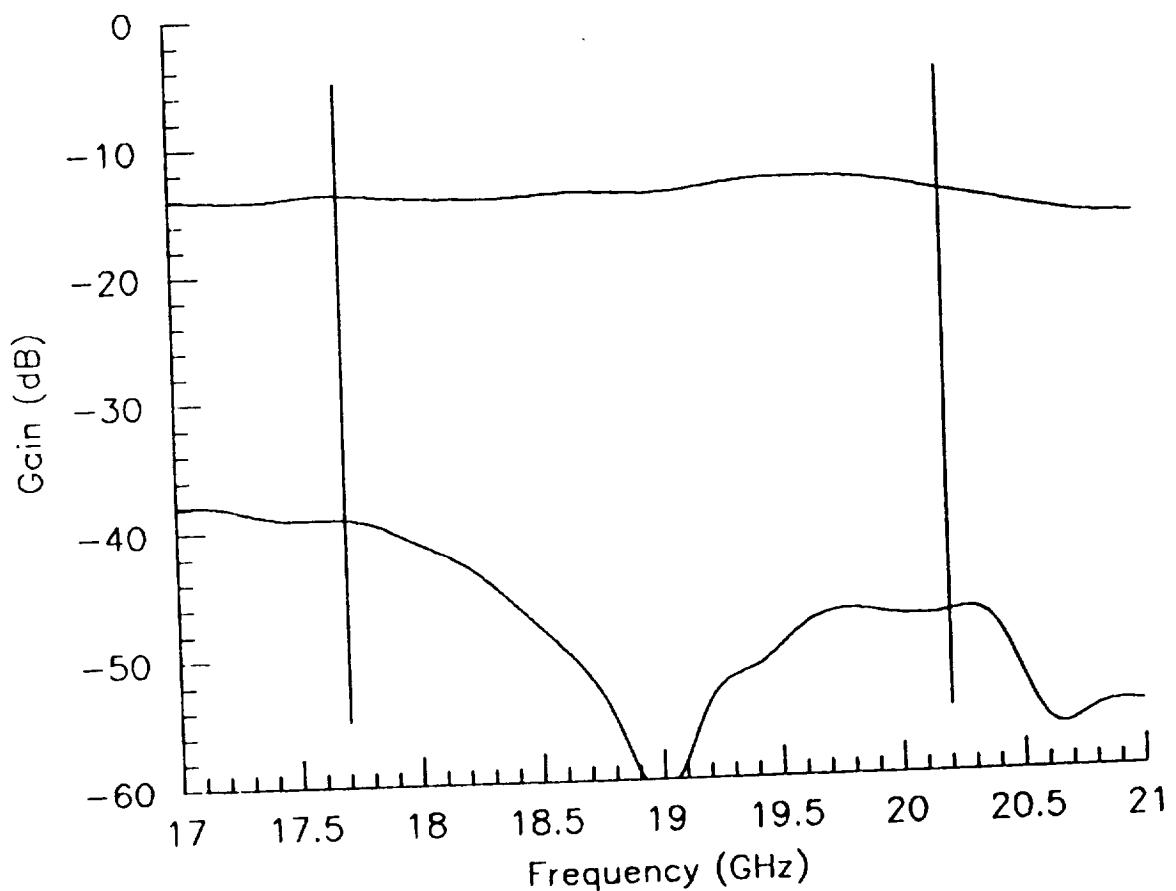


Figure 9.2-17) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

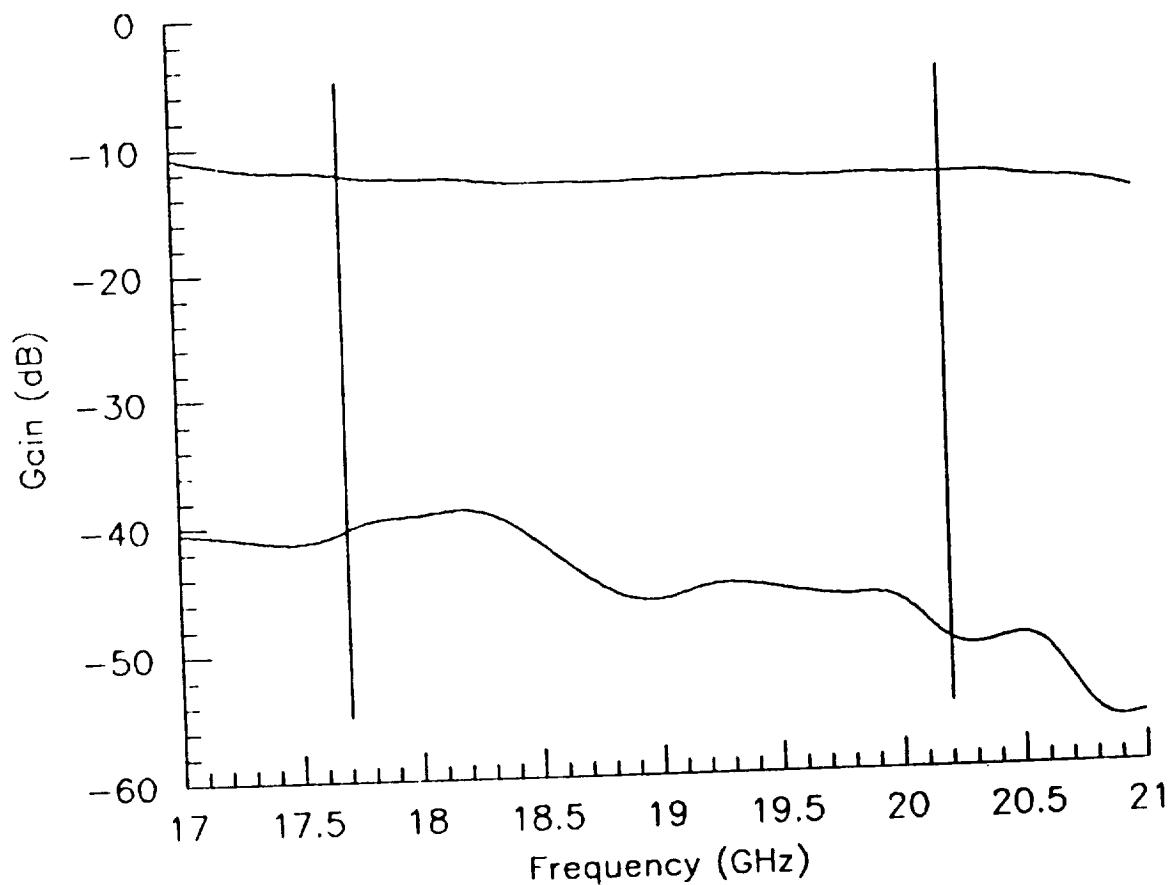


Figure 9.2-18) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

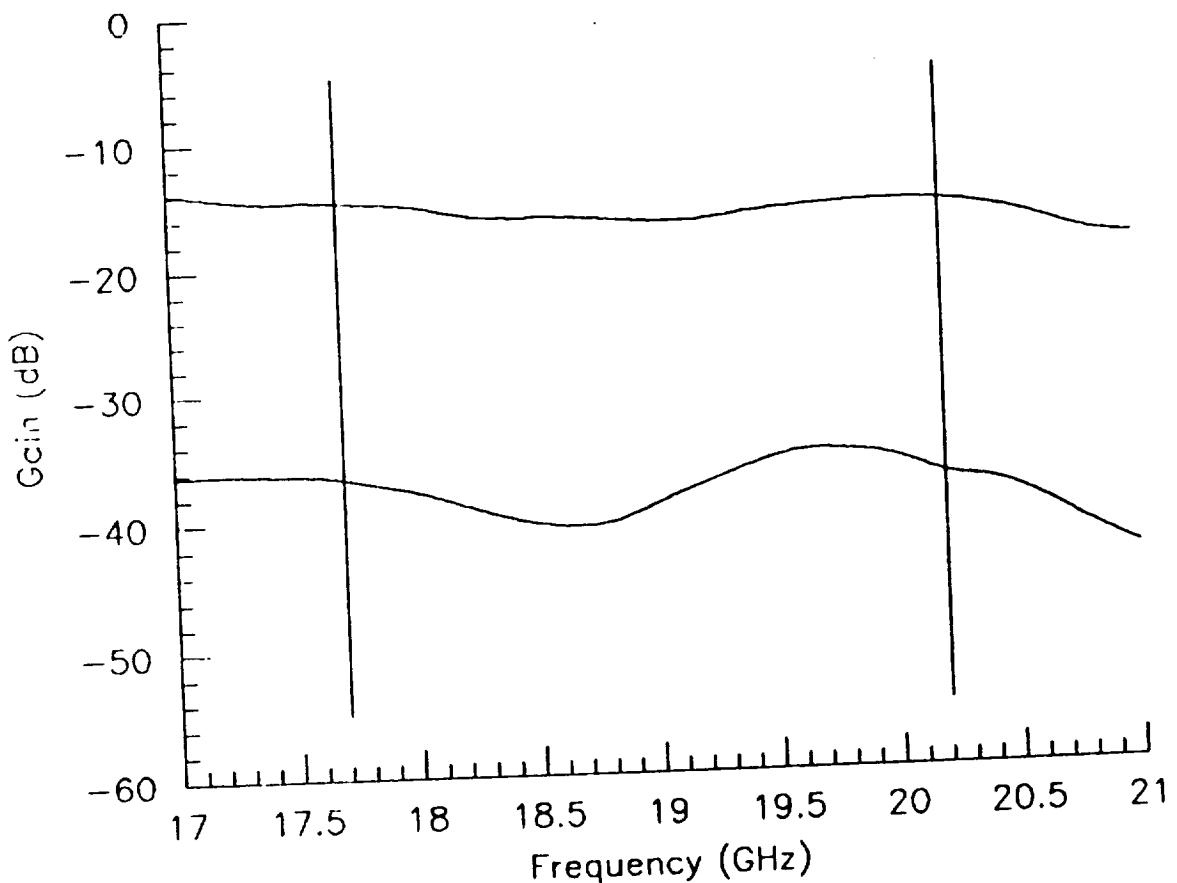


Figure 9.2-19) Measured Performance of the 3×3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

5b

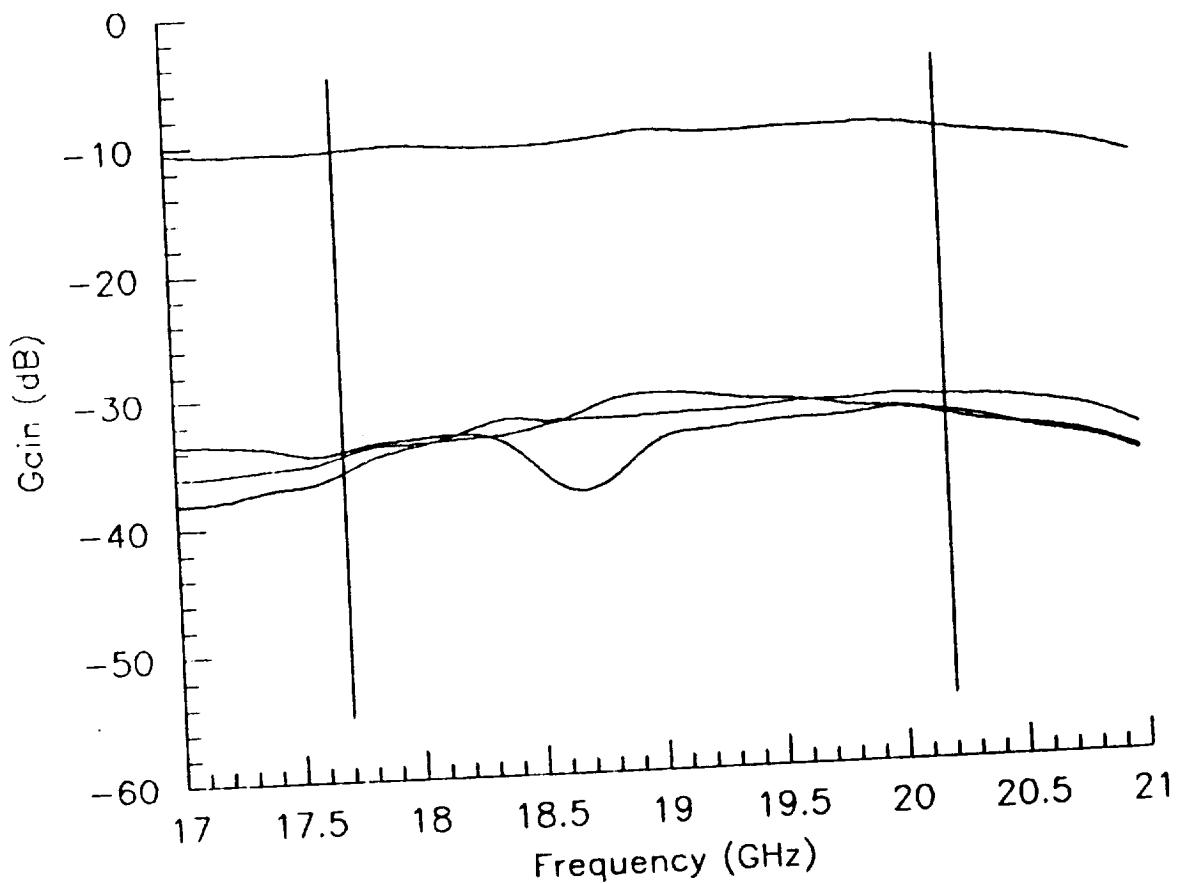


Figure 9.2-20) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

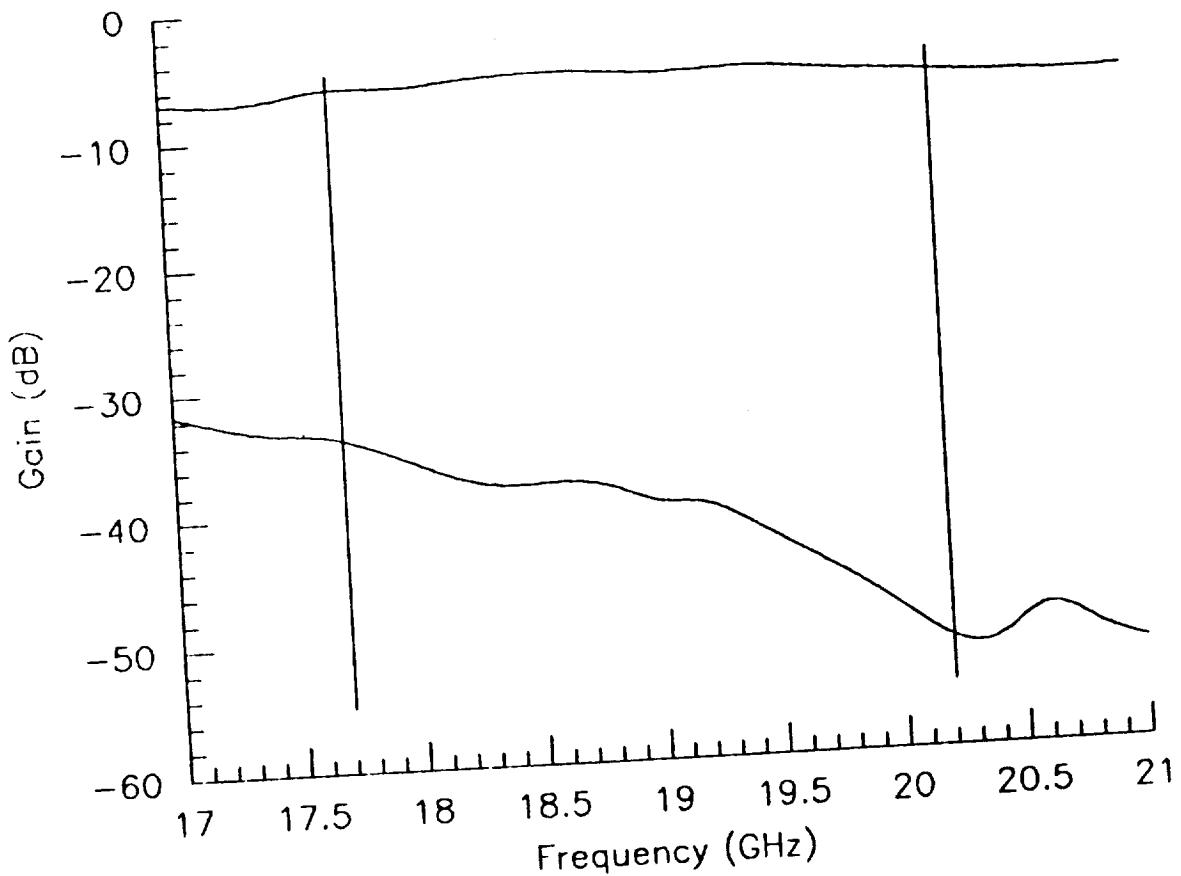


Figure 9.2-21) Measured Performance of the 3×3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

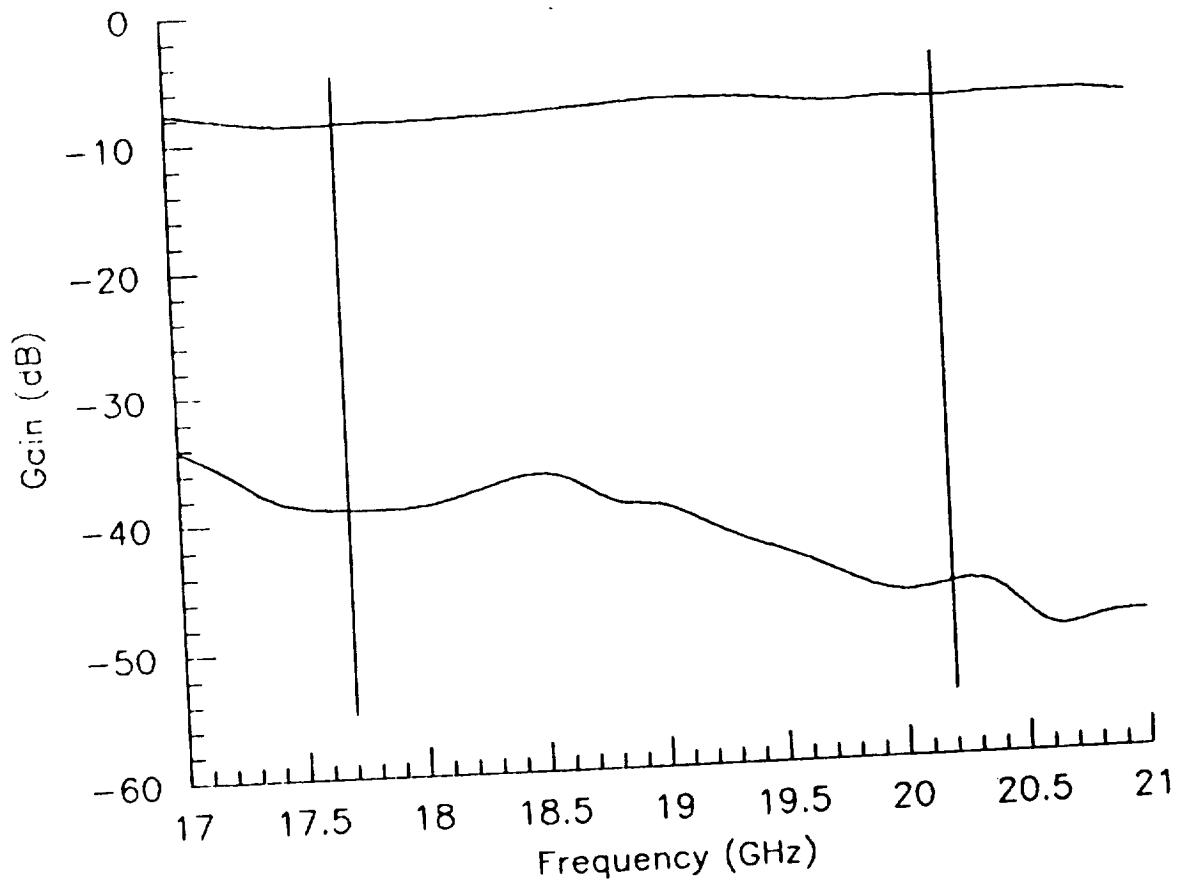


Figure 9.2-22) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

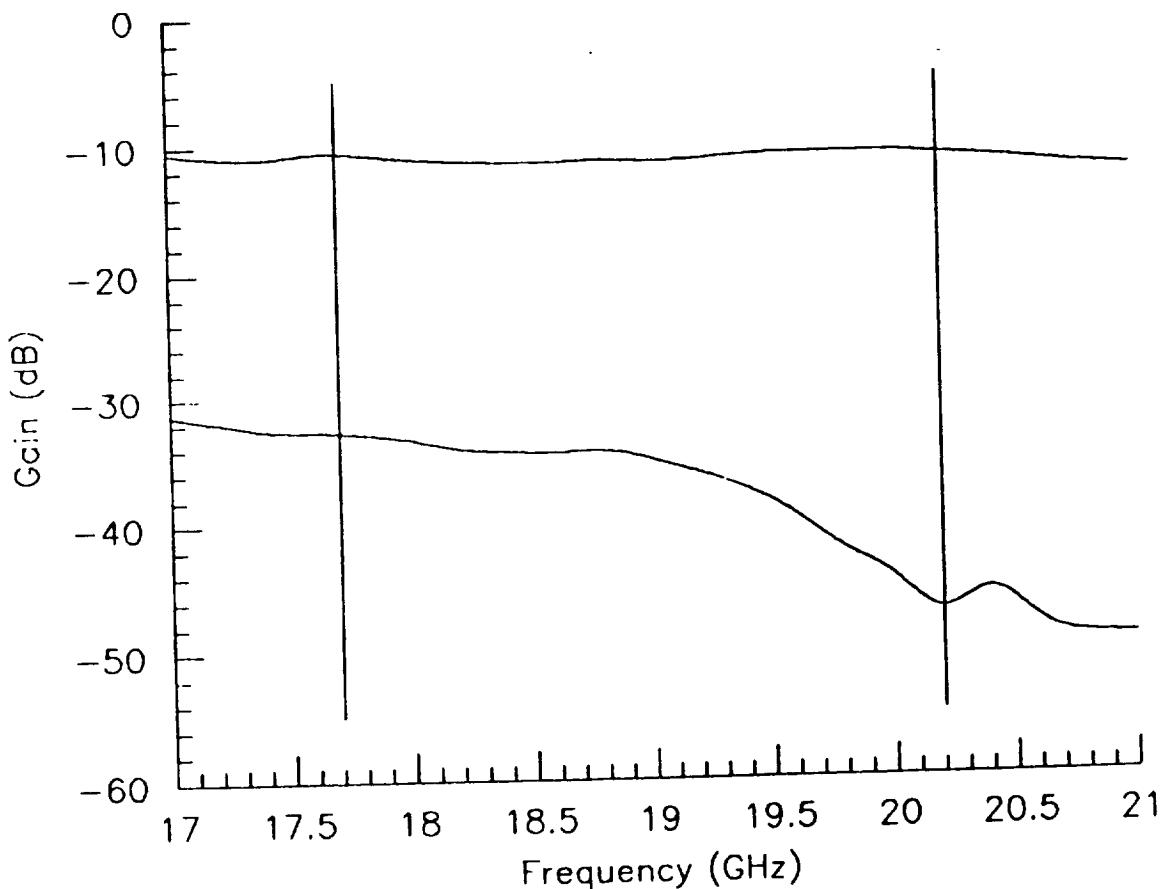


Figure 9.2-23) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

6c

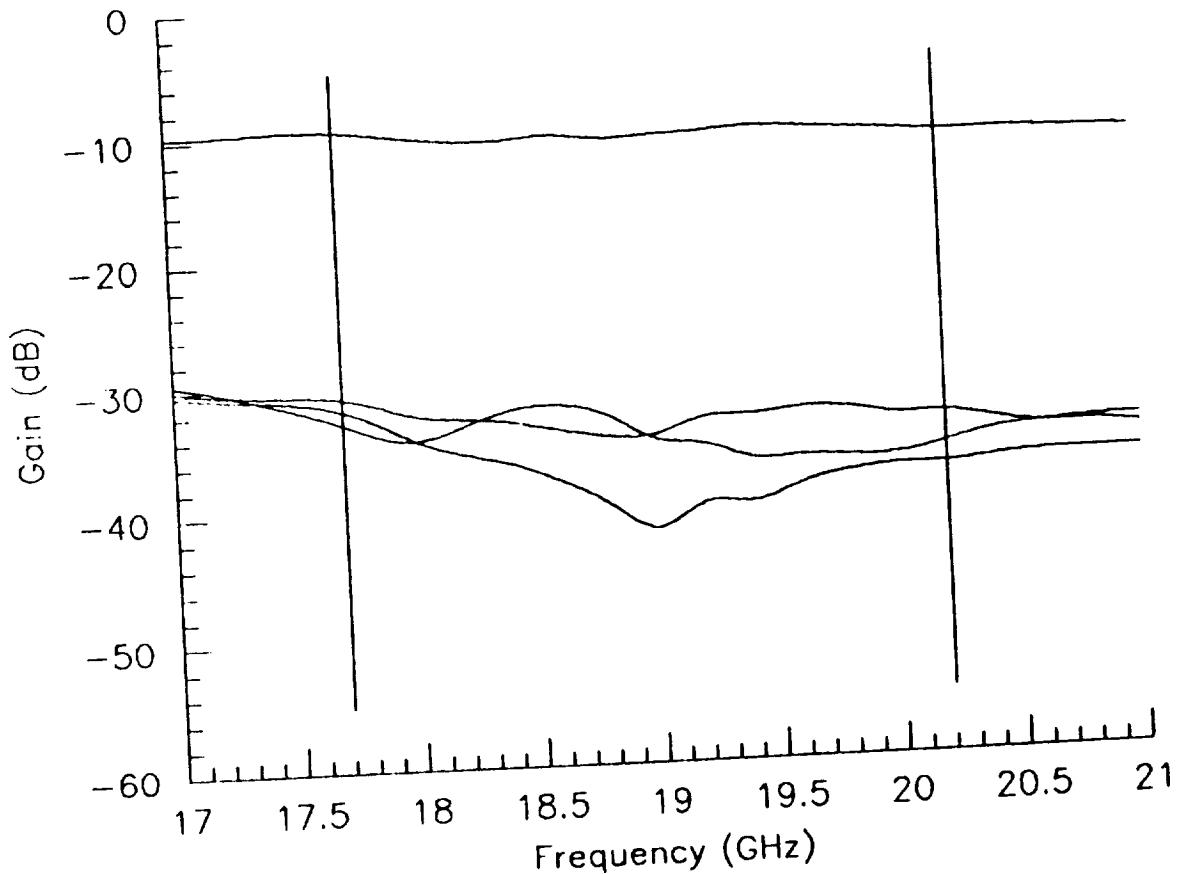


Figure 9.2-24) Measured Performance of the 3 x 3 Monolithic GaAs RF Switch Matrix Delivered to NASA Lewis Research Center

9.3) Measured Buffer Amplifier Performance

Six independently packaged buffer amplifiers were delivered under this program, and their measured gains are presented in Figures 9.3-1 through 9.3-6. They are intended for connection to the primary switching routes, i.e. on ports 1 through 3 and ports 10 through 12. The number at the top of each plot is the intended port connection.

All six packaged buffer amplifiers operate with a drain voltage of 3.5 volts on the V_d pin. The gate bias pin should remain disconnected since the chip gate bias connection is provided inside the package.

1

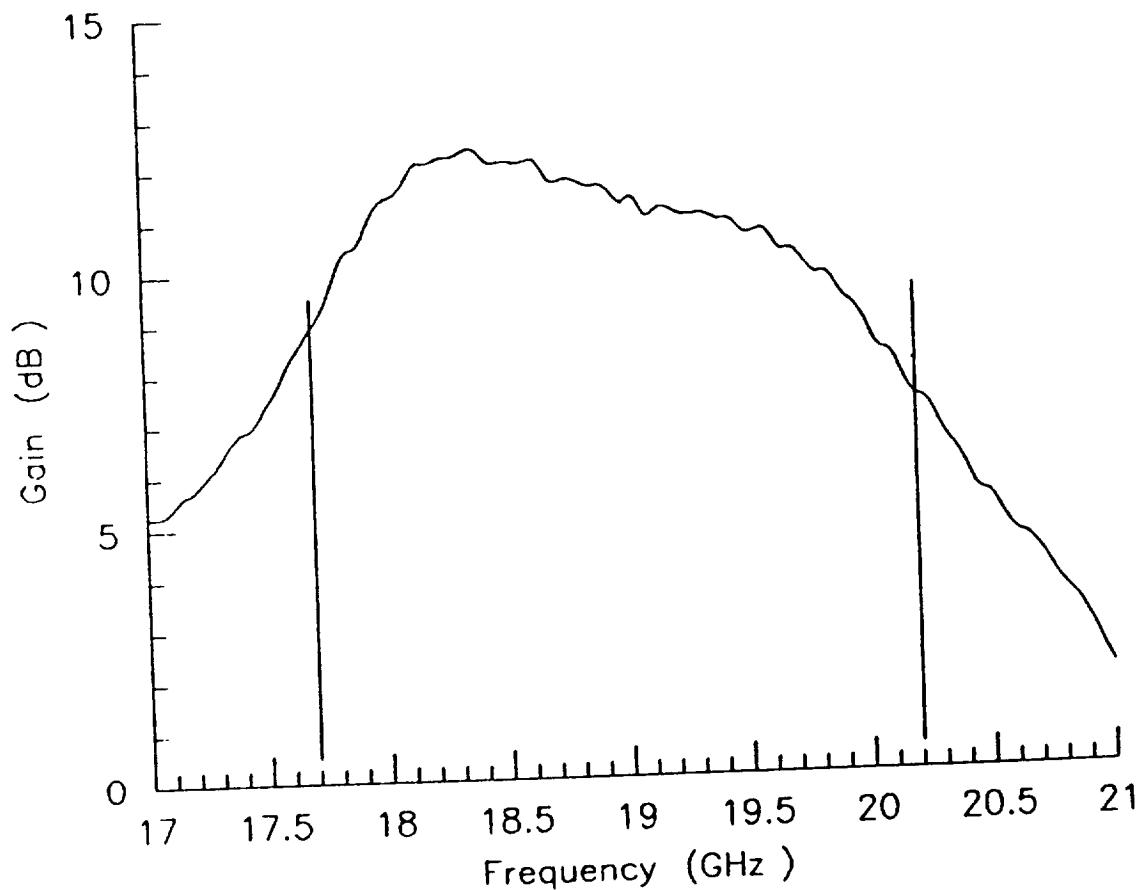


Figure 9.3-1) Measured Gain of the Buffer Amplifiers Delivered to NASA

2

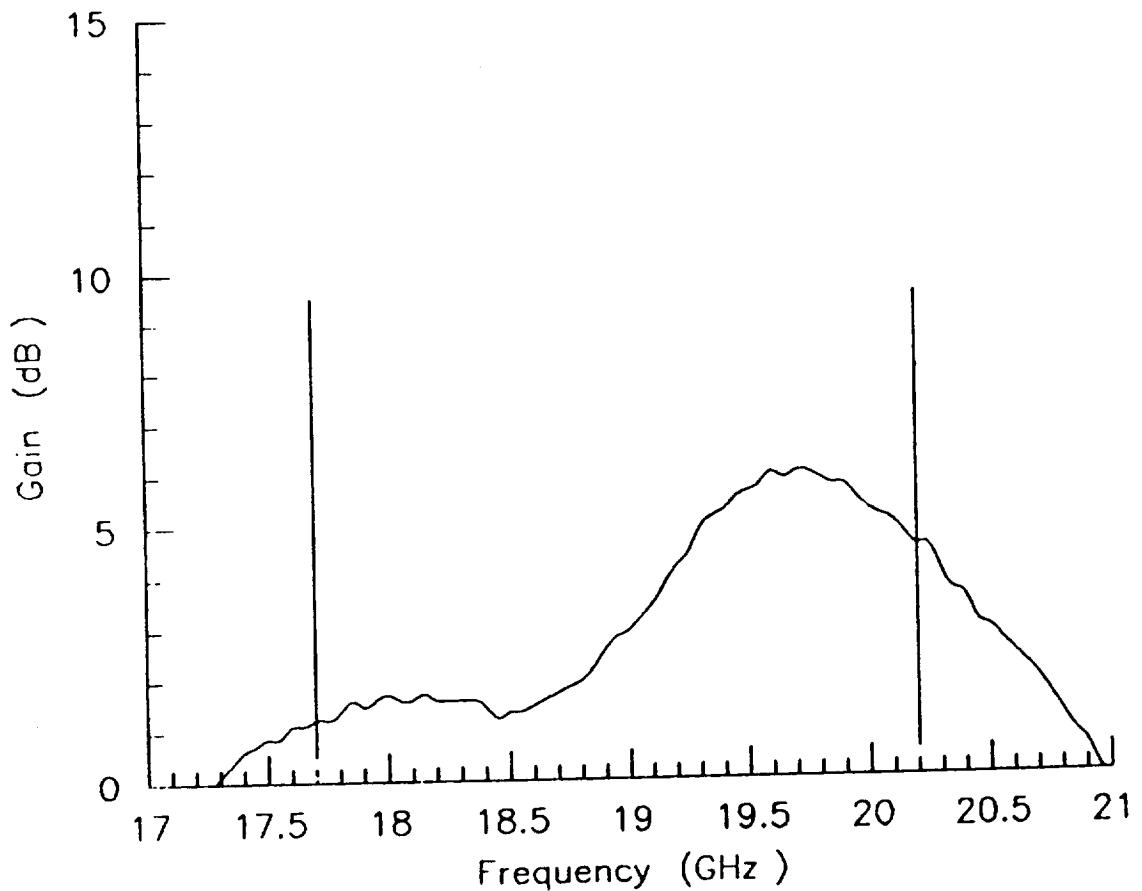


Figure 9.3-2) Measured Gain of the Buffer Amplifiers Delivered to NASA

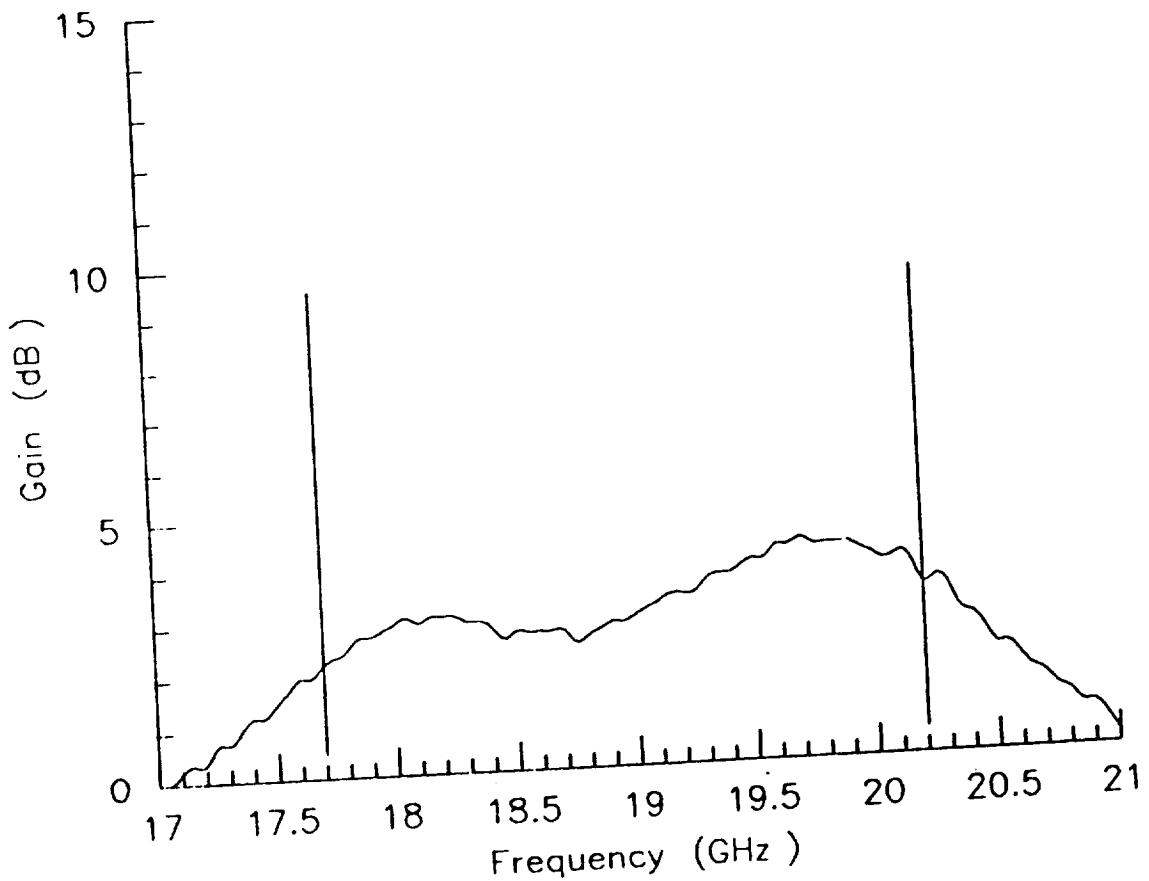


Figure 9.3-3) Measured Gain of the Buffer Amplifiers Delivered to NASA

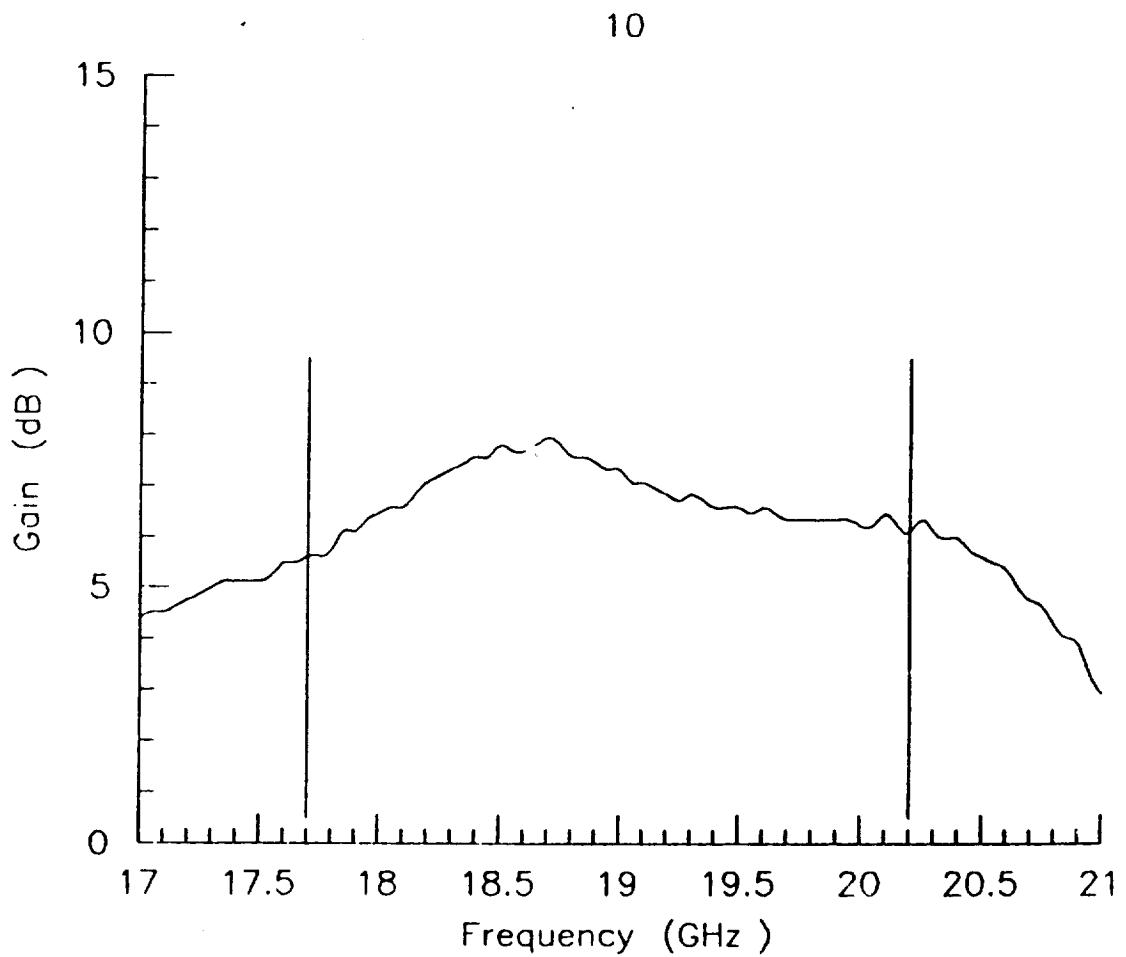


Figure 9.3-4) Measured Gain of the Buffer Amplifiers Delivered to NASA

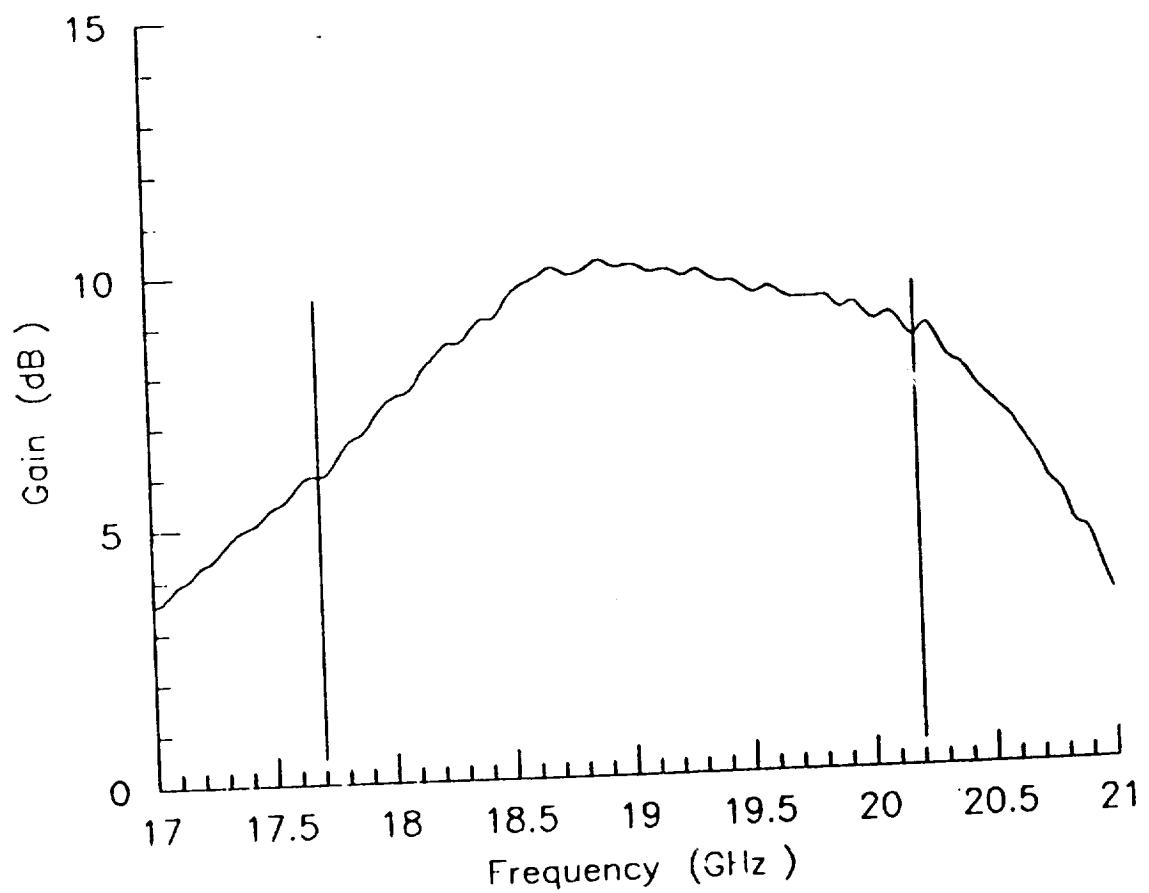


Figure 9.3-5) Measured Gain of the Buffer Amplifiers Delivered to NASA

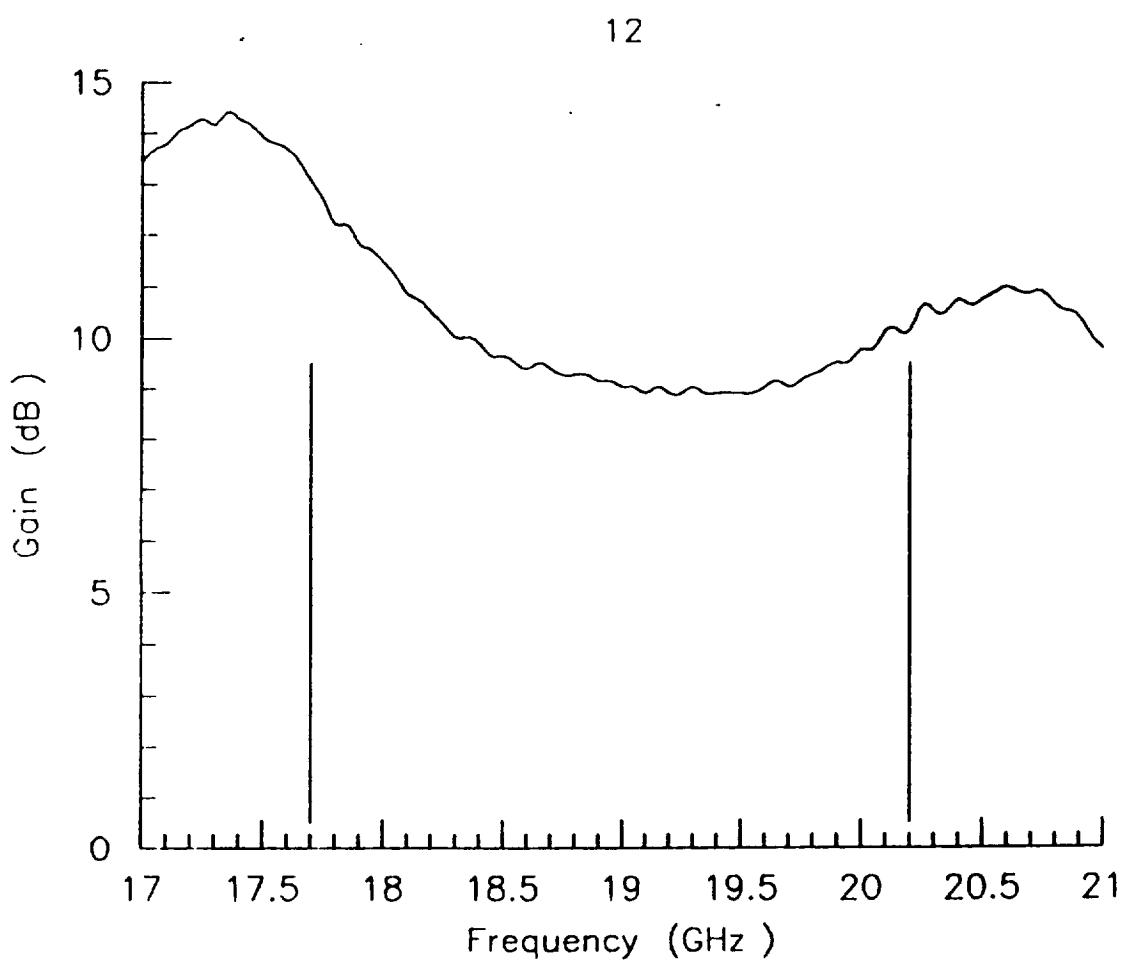


Figure 9.3-6) Measured Gain of the Buffer Amplifiers Delivered to NASA

9.4) Projected Performance of Integrated Subsystem

Although program constraints did not permit characterization of the merged buffer amplifiers/switch matrix, the gains of the merged subsystem was projected by numerically combining the results presented in sections 9.2 and 9.3. The results of this projection are presented in Figures 9.4-1 through 9.4-9, with the labeling convention the same as that utilized in section 9.2. Figure 9.4-10 is a composite plot of Figures 9.4-1 through 9.4-9, showing the approximately zero dB gain desired for the subsystem.

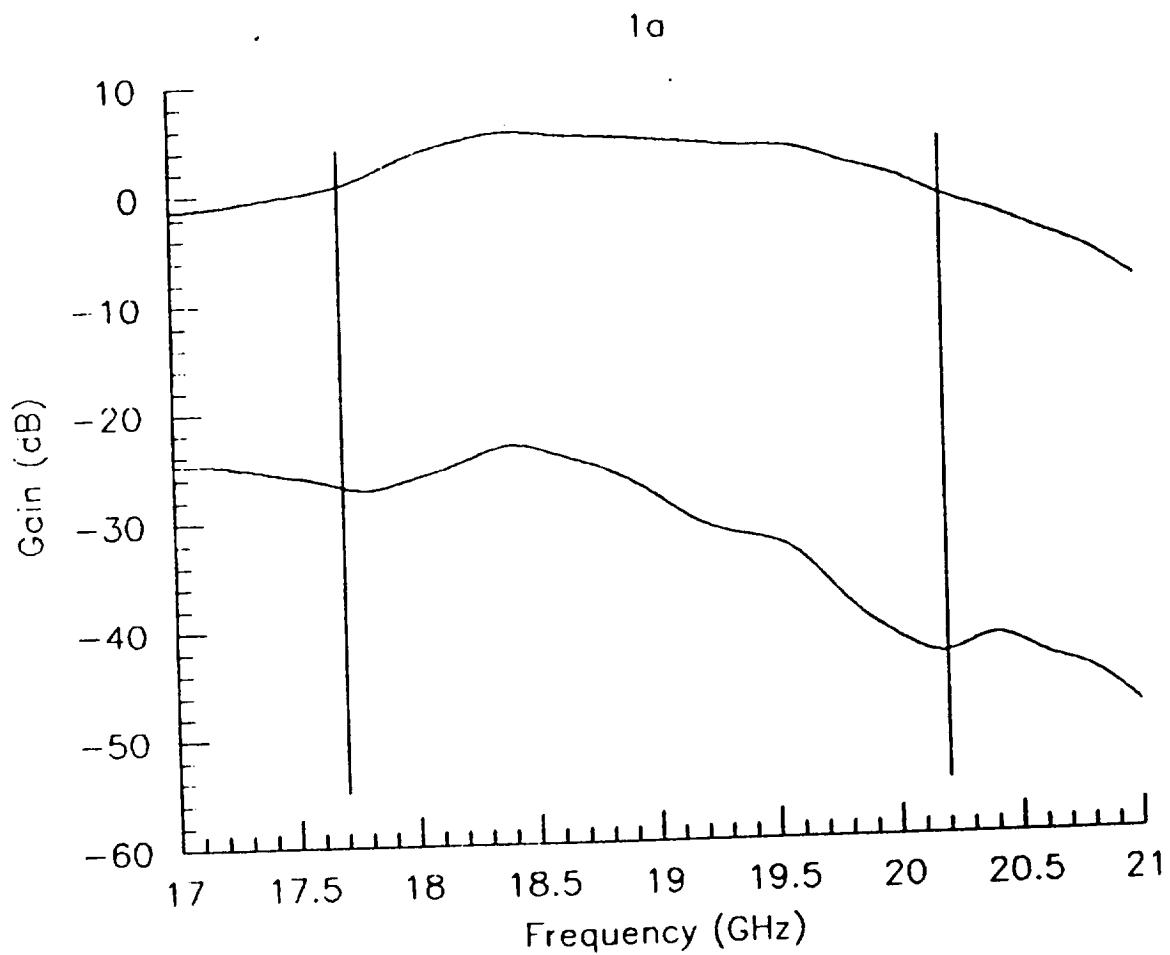


Figure 9.4-1) Projected Measured Performance of the 3 X 3 Subsystem
with Attached Buffer Amplifiers

1b

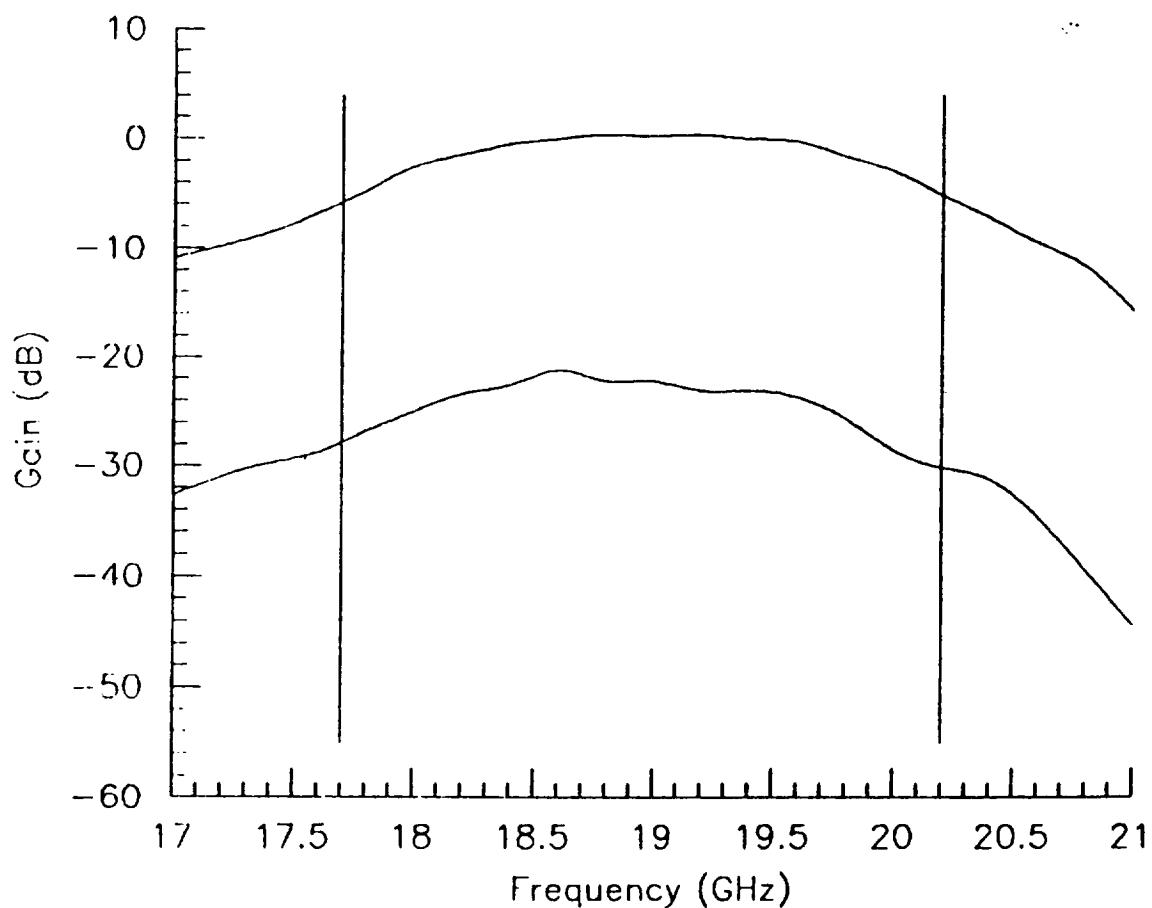


Figure 9.4-2) Projected Measured Performance of the 3 X 3 Subsystem
with Attached Buffer Amplifiers

1c

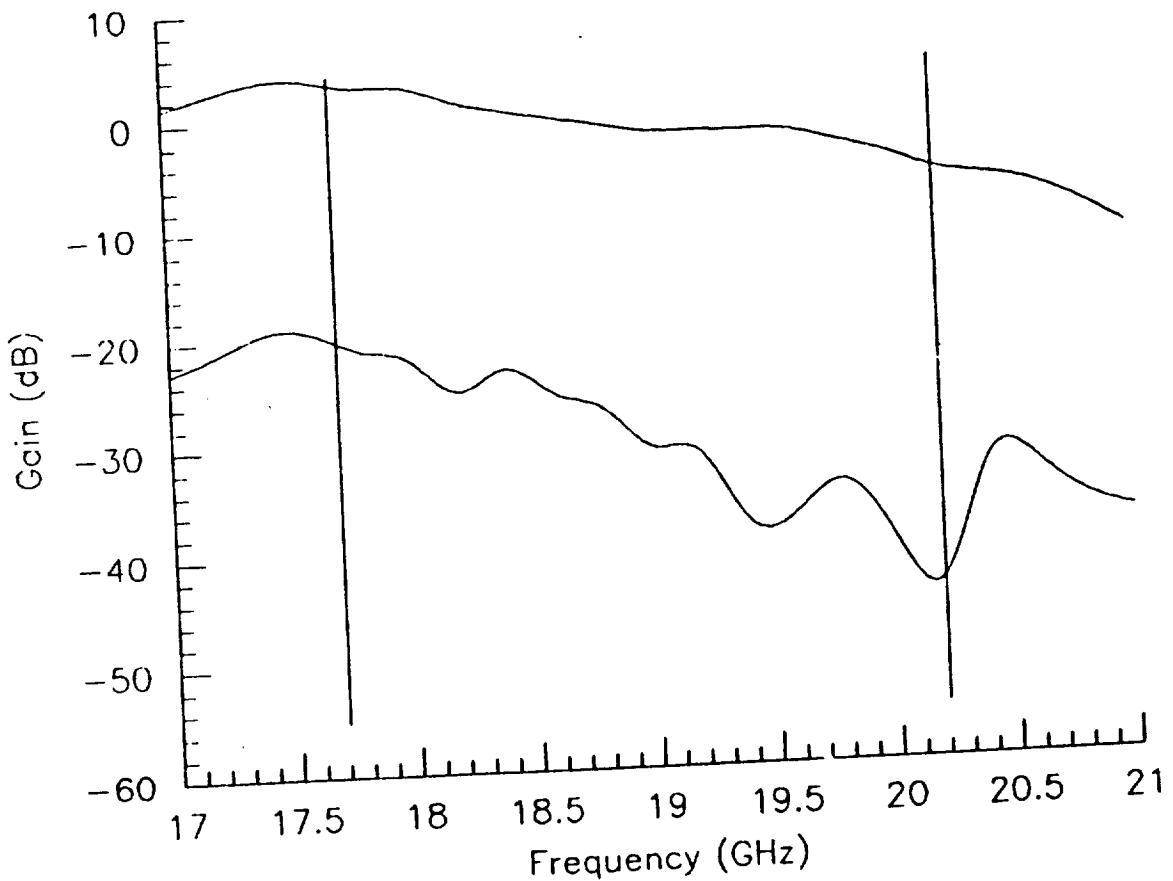


Figure 9.4-3) Projected Measured Performance of the 3 X 3 Subsystem
with Attached Buffer Amplifiers

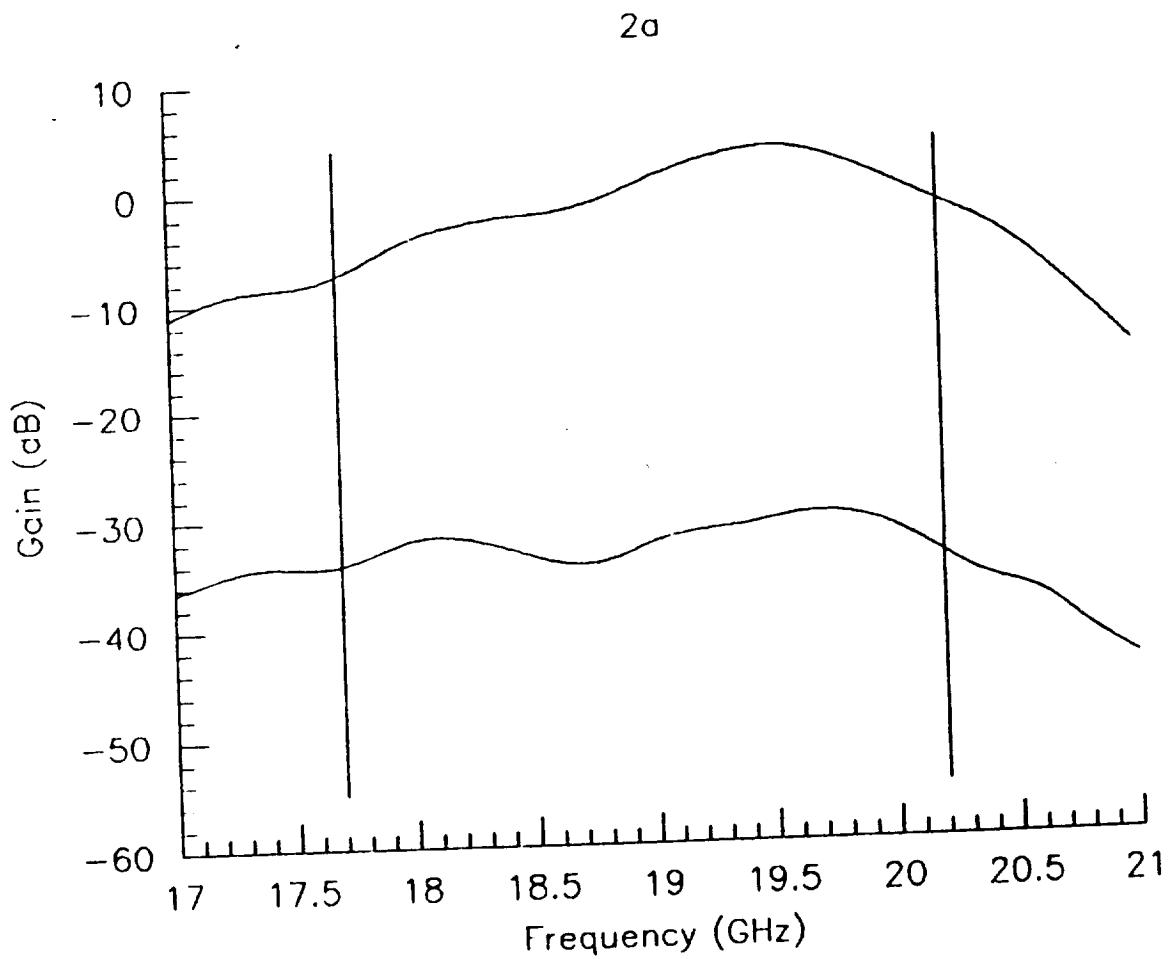


Figure 9.4-4) Projected Measured Performance of the 3 X 3 Subsystem
with Attached Buffer Amplifiers

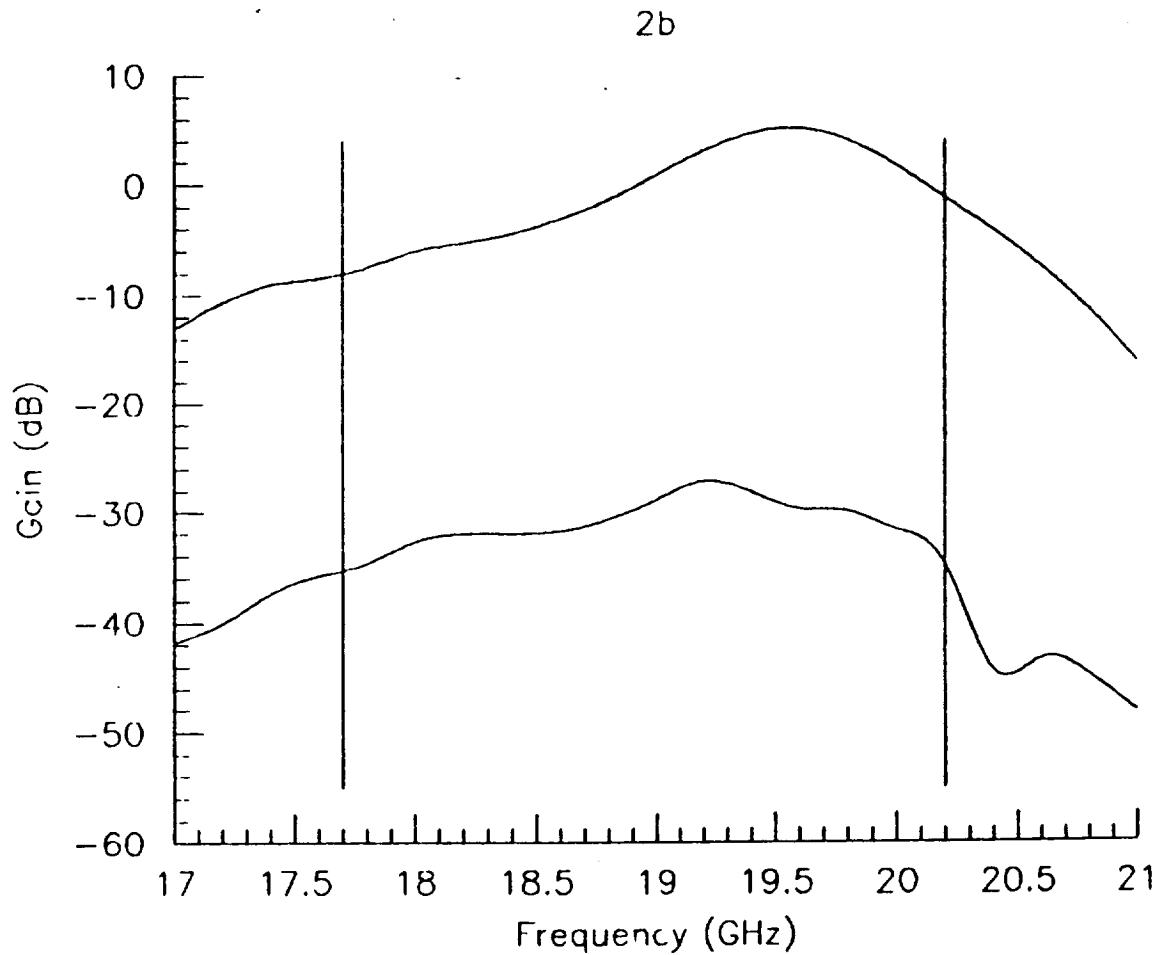


Figure 9.4-5) Projected Measured Performance of the 3 X 3 Subsystem
with Attached Buffer Amplifiers

2c

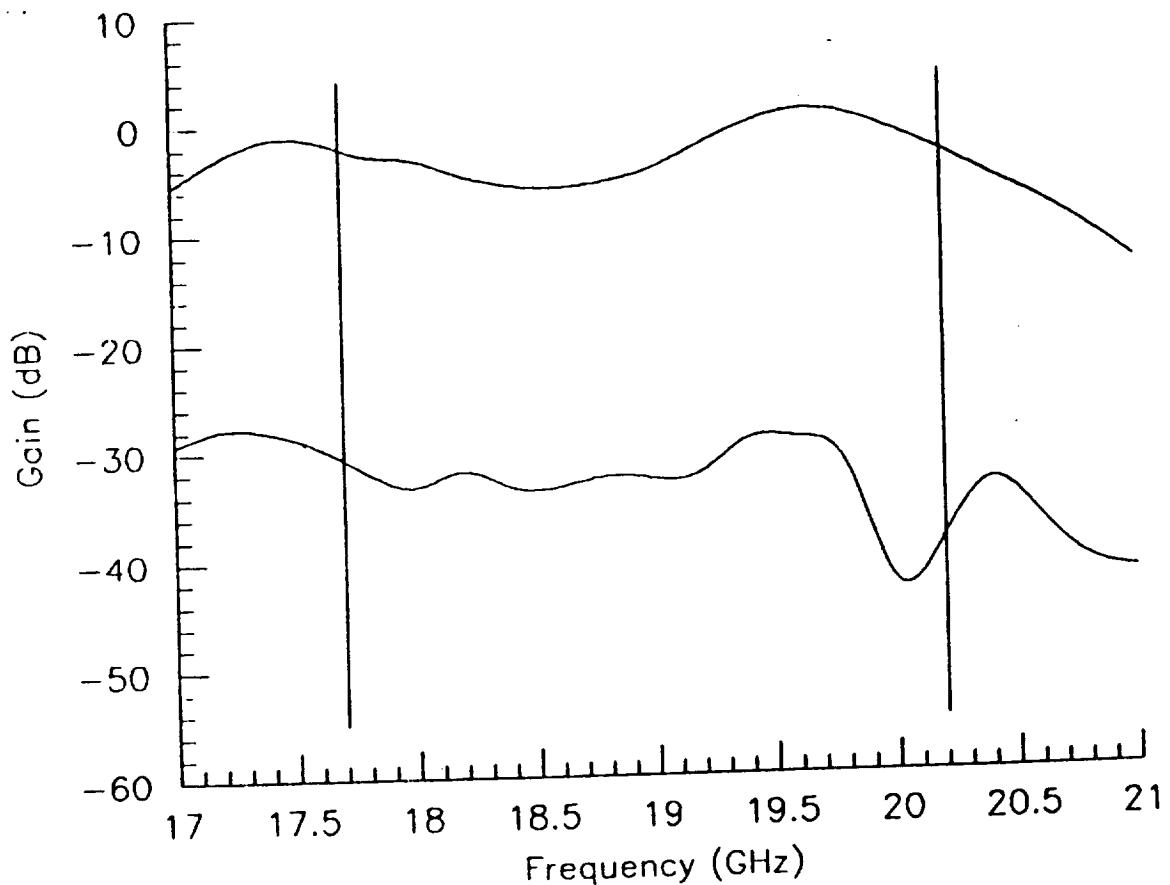


Figure 9.4-6) Projected Measured Performance of the 3 X 3 Subsystem
with Attached Buffer Amplifiers

3a

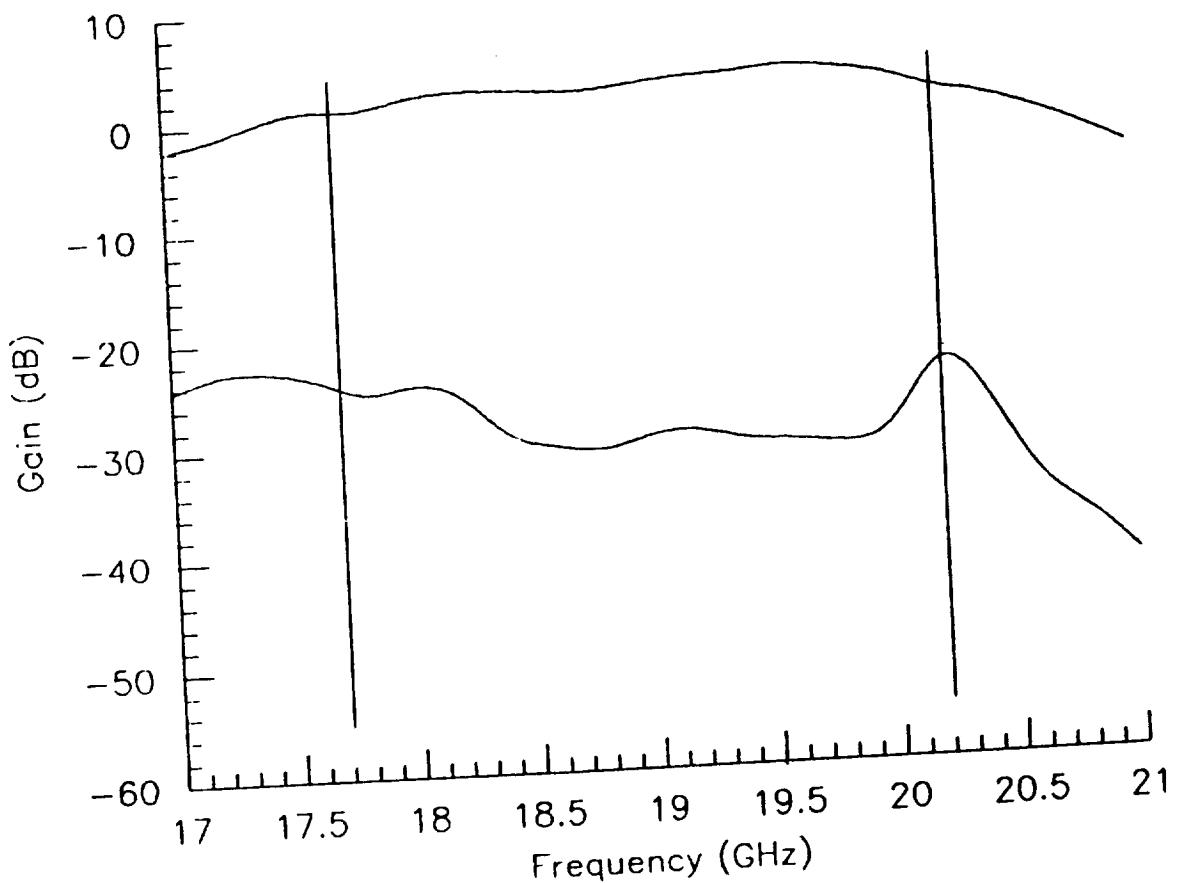


Figure 9.4-7) Projected Measured Performance of the 3 X 3 Subsystem
with Attached Buffer Amplifiers

3b

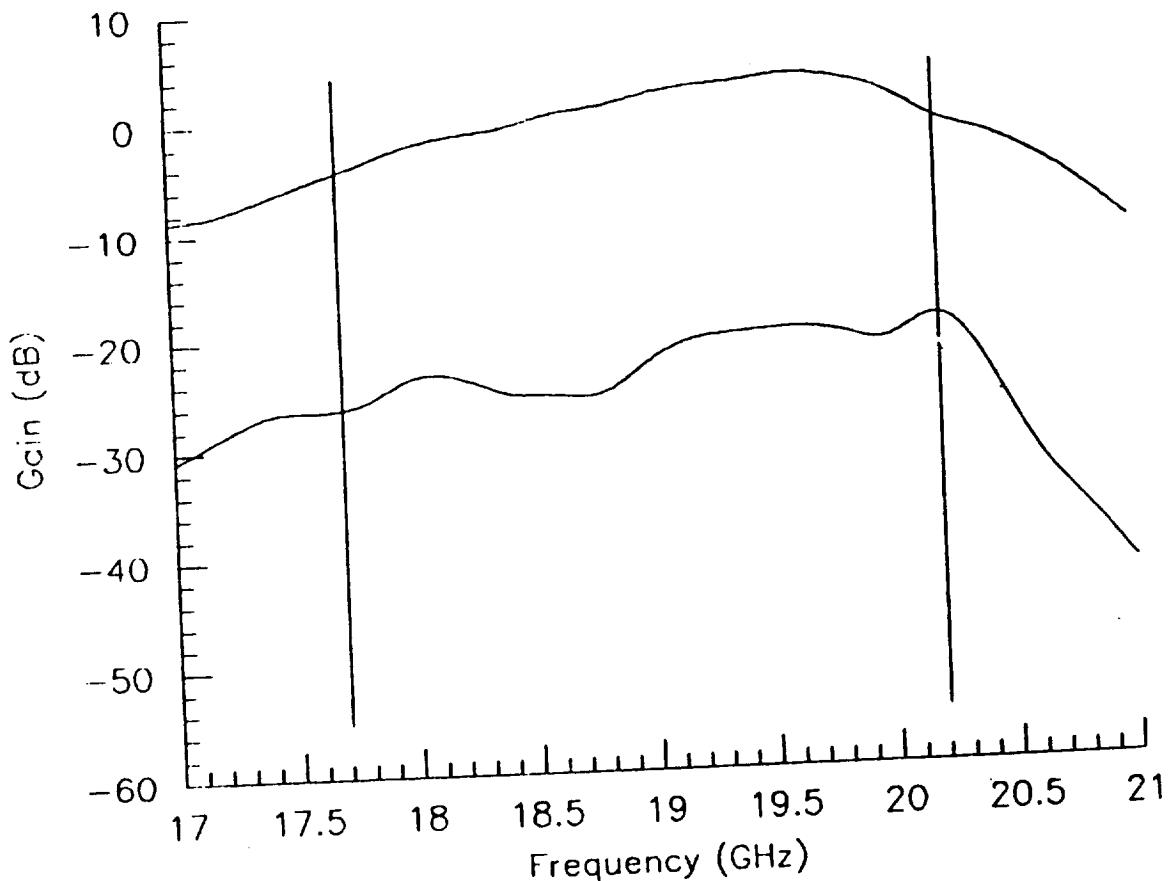


Figure 9.4-8) Projected Measured Performance of the 3 X 3 Subsystem
with Attached Buffer Amplifiers

3c

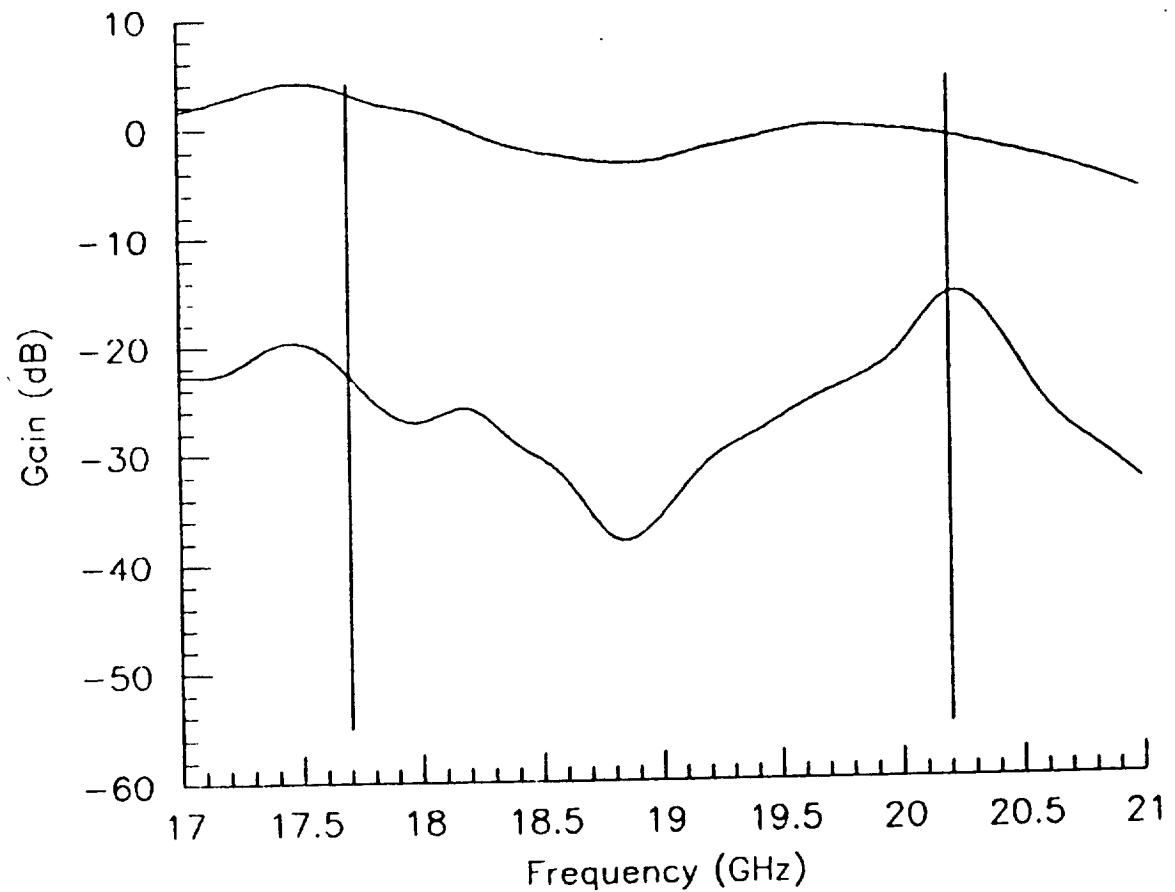


Figure 9.4-9) Projected Measured Performance of the 3 X 3 Subsystem
with Attached Buffer Amplifiers

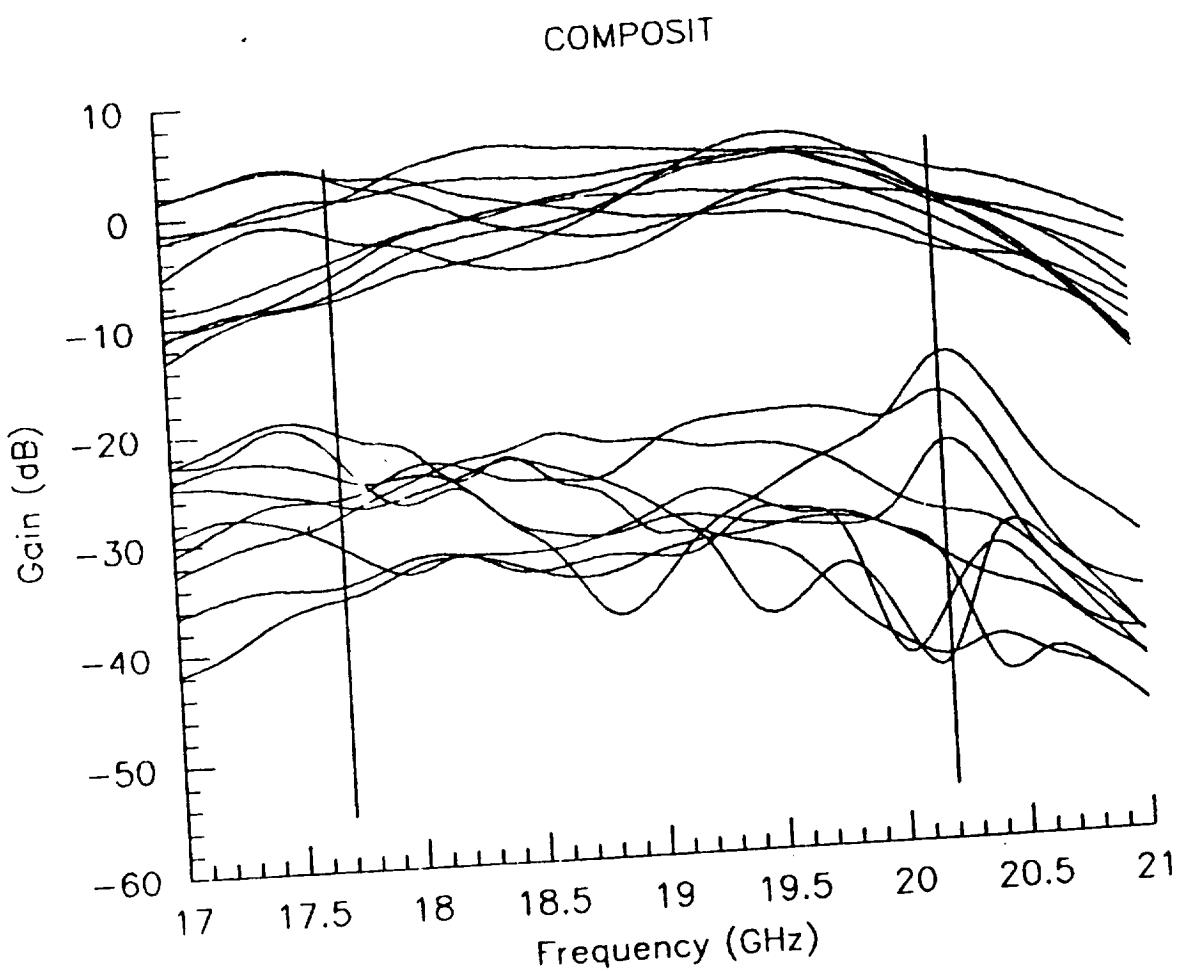


Figure 9.4-10) Composite Measured Performance of the 3 X 3 Subsystem with Attached Buffer Amplifiers

10) APPENDIX B: Preliminary Performance Estimates for the 10 X 10
Monolithic GaAs RF Switch Matrix

This section presents the predicted data for the 10 X 10 monolithic switch matrix described in section 6. Data format for the 40 port Scattering parameters is the same as that used throughout this report for the predicted performance of the 3 X 3 monolithic switch matrix. Included in this analysis are the fixed peripheral buffer amplifiers necessary for gain leveling. For simplicity, a fixed gain and reverse isolation over frequency was assumed for each amplifier. With gain slope compensation, which is also feasible, superior predicted performance could be obtained.

10.1) Through State

Table 10.1-1 presents predicted Scattering Parameters of the 40 port 10 X 10 GaAs monolithic switch matrix in the through state. In this state, all left hand input ports (ports 1 to 10) are routed to the right side (ports 21 to 30 respectively) and the top input ports (ports 11 to 20) are routed to the bottom output ports (ports 31 to 40 respectively).

10.2) Bypass State

Table 10.2-1 presents predicted Scattering Parameters of the 40 port 10 X 10 GaAs monolithic switch matrix in one of the many possible bypass states. In this state, all left hand input ports (ports 1 to 10) are routed to the bottom output ports (ports 31 to 40 respectively) and the top input ports (ports 11 to 20) are routed to the right hand output ports (ports 21 to 30 respectively).

10.3) Reverse Bypass State

Table 10.3-1 presents predicted Scattering Parameters of the 40 port 10 X 10 GaAs monolithic switch matrix in another of the many possible bypass states. In this state, all left hand input ports (ports 1 to 10) are routed to the bottom output ports (ports 31 to 40) and the top input ports (ports 11 to 20) are routed to the right hand output ports (ports 21 to 30). In this case, however, the routing is done in reverse order, i.e. port 1 is routed to port 40 and port 10 is routed to port 31. Similarly, port 11 is routed to port 30 and port 20 is routed to port 21. Therefore in this instance both the shortest and longest paths through the matrix are encountered. Note the excellent compensating effect of the buffer amplifiers.

11) APPENDIX C: Control Format for the Switch Matrix Control Box

11.1) External Controls

The following is a list of external controls available on the switch matrix controller:

ON/OFF SWITCH: Main Power Switch

RESET BUTTON: Initializes serial I/O port, all internal registers, all switch control memory locations, and sets IDLE ON, TDMA OFF, and ECHO OFF. Same as power on reset and RESET command.

STEP BUTTON: Turns off TDMA mode and Steps to next memory location. Output control lines are affected. Same as STEP command.

TDMA DIP SWITCH: The following TDMA dwell times are available:

RATE	S1,S2,S3
1 MHz	ON,ON,ON
250 KHz	OFF,ON,ON
15 KHz	ON,OFF,ON
1 KHz	OFF,OFF,ON
60 Hz	ON,ON,OFF
4 Hz	OFF,ON,OFF
1 Hz	ON,OFF,OFF
1/5 Hz	OFF,OFF,OFF

EXTERNAL AMP METER TOGGLE SWITCHES:

These switches allow the user to use external amp meters instead of the built in amp meters. When in the external mode, the banana jacks in the back of the MSC Box are used.

VARIABLE POWER SUPPLY ADJUSTMENTS:

The variable power supplies may be adjusted through holes in the back of the MSC Box.

11.2) Computer Commands

The following is a complete list of commands for the switch matrix controller and their meaning.

- CLEAR ALL: Turns off TDMA mode. Sets all switch control memories to F (Hex). Turns off all cross points. Latched output control lines are not affected.
- CLEAR(K): Turns off TDMA mode. Sets all ten switch output-port-control memories at address K to F (Hex). Turns off all cross points at address K. Latched output control lines are not affected.
- CLEAR(J,K): Turns off TDMA mode. Set output port J at address K to F (Hex). Disconnects all input ports from output port J at address K. Latched output control lines are not affected.
- CLEAR(J,A1-A2): Turns off TDMA mode. Set output port J from address A1 to address A2 to F (Hex). Disconnects all input ports from output port J between addresses A1 and A2. Latched output control lines are not affected.
- ECHO ON: Turns Echo mode ON. Characters will be echoed back to terminal or commuter when Echo is ON.
- ECHO OFF: Turns Echo mode OFF. ECHO is off at power up.
- IDLE ON: Turns Idle mode ON. IDLE is ON at power up. Output drives are at zero volts when Idle is ON. Memory remains unaltered.
- IDLE OFF: Turns Idle OFF. Output control lines are at +V and -V when Idle is OFF. Memory remains unaltered.

READ ALL: Turns off TDMA mode. Reads switch control memory locations for all output-port-control memories. Latched output control lines are not affected.

READ(K): Turns off TDMA mode. Reads all ten switch output-port-control memories at address K. Latched output control lines are not affected.

READ(J,K): Turns off TDMA mode. Reads output port J at address K. Latched output control lines are not affected.

READ(J,A1-A2): Turns off TDMA mode. Reads output port J from address A1 to address A2. Latched output control lines are not affected. RUN: Not Used.

RESET: Initializes serial I/O port. All internal registers, all switch control memory locations, and sets IDLE ON, TDMA OFF, and ECHO OFF. Same as power on reset and RESET button.

SET(I,K): Turns off TDMA mode. Sets input port I to all output ports at address K. Latched output control lines are not affected.

SET(I,A1-A2): Turns off TDMA mode. Sets input port I to all output ports from address A1 to Address A2. Latched output control lines are not affected.

STATIC(K): Turns off TDMA mode, all control lines are set and latched to the matrix configuration specified at address K.

STEP: Turns off TDMA mode and Steps to next memory location.
Output control lines are affected. Same as STEP button.

TDMA ON: Turns on TDMA mode. Output control lines are latched according to information in the output-port-control memories. The memories are cycled at an adjustable rate which is selected using the external TDMA DIP switch.

TDMA OFF: Turns off TDMA mode.

2

FOLDOUT FRAME

IC GaAs RF SWITCH
AMPLIFIERS

	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
7	205	213	221	229	237	245	253	260	144	152	160	168	176	184	192	200	208	215
6	-285	-394	-142	-252	-358	-471	-210	-337	-222	-330	-79	-188	-296	-406	-152	-265	-364	-490
0	197	205	213	221	229	237	245	253	137	145	153	161	169	177	185	193	200	208
-6	-159	-268	-376	-126	-232	-345	-444	-211	-96	-204	-313	-62	-170	-280	-386	-139	-239	-366
4	80	197	205	213	221	229	237	245	129	137	145	153	161	169	177	184	193	200
2	-6	-168	-276	-386	-132	-246	-345	-472	3	-105	-213	-322	-70	-180	-286	-400	-139	-266
2	173	80	197	205	213	221	229	237	121	129	137	145	153	161	169	177	185	192
3	-251	-6	-163	-273	-379	-133	-232	-359	-243	7	-100	-209	-317	-67	-173	-286	-386	-153
0	171	174	80	197	205	213	221	229	113	121	129	137	145	153	161	169	177	184
39	34	-252	-6	-167	-273	-386	-125	-252	-137	-245	5	-103	-211	-321	-67	-180	-279	-406
68	169	172	173	80	197	205	213	221	105	113	121	129	137	145	153	161	169	176
13	-38	34	-251	-6	-163	-276	-376	-143	-27	-136	-244	6	-101	-211	-317	-70	-170	-297
66	167	170	172	174	80	197	205	213	97	105	113	121	129	137	145	153	161	168
87	-112	-39	34	-252	-6	-168	-267	-394	80	-27	-136	-245	6	-103	-209	-322	-61	-188
64	165	167	169	171	173	80	197	205	89	97	105	113	121	129	137	145	153	160
99	-185	-112	-38	34	-251	-6	-159	-286	-170	80	-27	-136	-244	5	-100	-213	-313	-80
62	164	166	168	170	172	174	80	197	81	89	97	105	113	121	129	137	145	152
24	99	-187	-113	-39	33	-252	-6	-177	-61	-170	80	-27	-136	-245	7	-105	-204	-331
59	161	163	165	167	169	171	173	80	73	81	89	97	105	113	121	129	137	144
46	28	101	-184	-111	-37	36	-250	-6	46	-61	-170	80	-27	-137	-243	3	-95	-222
52	160	168	176	184	192	200	208	215	80	197	205	213	221	229	237	245	253	260
330	-79	-188	-296	-406	-152	-265	-364	-490	-6	-176	-285	-394	-142	-252	-358	-471	-210	-337
45	153	161	169	177	185	193	200	208	173	80	197	205	213	221	229	237	245	253
204	-313	-62	-170	-280	-386	-139	-239	-366	-250	-6	-159	-268	-376	-126	-232	-345	-444	-211
137	145	153	161	169	177	184	193	200	171	174	80	197	205	213	221	229	237	245
105	-213	-322	-70	-180	-286	-400	-139	-266	36	-252	-6	-168	-276	-386	-132	-246	-345	-472
129	137	145	153	161	169	177	185	192	169	172	173	80	197	205	213	221	229	237
7	-100	-209	-317	-67	-173	-286	-386	-153	-37	33	-251	-6	-163	-273	-379	-133	-232	-359
21	129	137	145	153	161	169	177	184	167	170	171	174	80	197	205	213	221	229
245	5	-103	-211	-321	-67	-180	-279	-406	-111	-39	34	-252	-6	-167	-273	-386	-125	-252
113	121	129	137	145	153	161	169	176	165	168	169	172	173	80	197	205	213	221
136	-244	6	-101	-211	-317	-70	-170	-297	-184	-113	-38	34	-251	-6	-163	-276	-376	-143
105	113	121	129	137	145	153	161	168	163	166	167	170	172	174	80	197	205	213
-27	-136	-245	6	-103	-209	-322	-61	-188	101	-187	-112	-39	34	-252	-6	-168	-267	-394
97	105	113	121	129	137	145	153	160	161	164	165	167	169	171	173	80	197	205
80	-27	-136	-244	5	-100	-213	-313	-80	28	99	-185	-112	-38	34	-251	-6	-159	-286
89	97	105	113	121	129	137	145	152	159	162	164	166	168	170	172	174	80	197
170	80	-27	-136	-245	7	-105	-204	-331	-46	24	99	-187	-113	-39	33	-252	-6	-177

FOLDOUT FRAME

TABLE 10.1-1
PREDICTED PERFORMANCE OF THE 10 X 10 MONOLITIC
MATRIX IN THE THROUGH STATE WITH BUFF

0000000000
0000000000
0000000000
0000000000
0000000000
0000000000
0000000000
0000000000
0000000000
0000000000

F = 17.50

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
1)	35	153	159	165	171	177	183	189	195	200	79	85	91	97	103	109	115	121	127	132	80	
	-426	-241	-314	-388	-101	-175	-249	-322	-37	-108	-312	-386	-100	-173	-247	-320	-34	-107	-182	-253	-6	
2)	145	33	151	157	163	169	175	181	187	193	77	83	89	95	101	107	113	119	125	130	173	
	-241	-391	-188	-262	-336	-49	-123	-196	-271	17	-386	-100	-173	-247	-320	-34	-108	-181	-256	32	-250	
3)	143	143	31	149	155	161	167	173	179	185	75	81	87	93	99	105	111	117	123	128	171	
	-314	-188	-356	-162	-236	-309	-23	-96	-171	-242	-100	-173	-247	-320	-34	-108	-181	-254	30	-40	36	
4)	141	141	141	29	147	153	159	165	171	177	73	79	85	91	97	103	109	115	121	126	169	
	-388	-262	-162	-321	-123	-196	-270	16	-58	-129	-173	-247	-320	-34	-108	-181	-255	31	-43	-114	-37	
5)	139	139	139	139	27	145	151	157	163	169	71	77	83	89	95	101	107	113	119	124	167	
	-101	-336	-236	-123	-286	-90	-164	-237	47	-23	-247	-320	-34	-108	-181	-255	30	-42	-117	-188	-111	
6)	137	137	137	137	137	25	143	149	155	161	69	75	81	87	93	99	105	111	117	122	165	
	-175	-49	-309	-196	-90	-251	-54	-127	-202	86	-320	-34	-108	-181	-255	31	-42	-115	-190	98	-184	
7)	135	135	135	135	135	23	141	147	153	167	73	79	85	91	97	103	109	115	120	163		
	-249	-123	-23	-270	-164	-54	-216	-19	-94	-165	-34	-108	-181	-255	30	-42	-116	-189	95	24	101	
8)	133	133	133	133	133	133	133	21	139	145	65	71	77	83	89	95	101	107	113	118	161	
	-322	-196	-96	16	-237	-127	-19	-181	14	-56	-107	-181	-254	31	-42	-115	-189	97	22	-48	28	
9)	131	131	131	131	131	131	131	131	131	19	137	63	69	75	81	87	93	99	105	111	117	159
	-37	-271	-171	-58	47	-202	-94	14	-146	51	-182	-256	30	-43	-117	-190	95	22	-52	-123	-46	
10)	128	129	129	129	129	129	129	129	129	17	60	66	72	78	84	90	96	102	109	114	157	
	-108	17	-242	-129	-23	86	-165	-56	51	-111	-253	32	-40	-114	-188	98	24	-48	-123	164	-117	
11)	79	85	91	97	103	109	115	121	127	132	35	153	159	165	171	177	183	189	195	200	144	
	-312	-386	-100	-173	-247	-320	-34	-107	-182	-253	-426	-241	-314	-388	-101	-175	-249	-322	-37	-108	-222	
12)	77	83	89	95	101	107	113	119	125	130	145	33	151	157	163	169	175	181	187	193	137	
	-386	-100	-173	-247	-320	-34	-108	-181	-256	32	-241	-391	-188	-262	-336	-49	-123	-196	-271	17	-96	
13)	75	81	87	93	99	105	111	117	123	128	143	143	31	149	155	161	167	173	179	185	129	
	-100	-173	-247	-320	-34	-108	-181	-254	30	-40	-314	-188	-356	-162	-236	-309	-23	-96	-171	-242	3	
14)	73	79	85	91	97	103	109	115	121	126	141	141	29	147	153	159	165	171	177	121		
	-173	-247	-320	-34	-108	-181	-255	31	-43	-114	-388	-262	-162	-321	-123	-196	-270	16	-58	-129	-243	
15)	71	77	83	89	95	101	107	113	119	124	139	139	139	139	139	27	145	151	157	163	169	113
	-247	-320	-34	-108	-181	-255	30	-42	-117	-188	-101	-336	-236	-123	-286	-90	-164	-237	47	-23	-137	
16)	69	75	81	87	93	99	105	111	117	122	137	137	137	137	137	25	143	149	155	161	166	105
	-320	-34	-108	-181	-255	31	-42	-115	-190	98	-175	-49	-309	-196	-90	-251	-54	-127	-202	86	-27	
17)	67	73	79	85	91	97	103	109	115	120	135	135	135	135	135	23	141	147	153	160	166	80
	-34	-108	-181	-255	30	-42	-116	-189	95	24	-249	-123	-23	-270	-164	-54	-216	-19	-94	-165	-165	
18)	65	71	77	83	89	95	101	107	113	118	133	133	133	133	133	21	139	145	149	155	161	89
	-107	-181	-254	31	-42	-115	-189	97	22	-48	-322	-196	-96	16	-237	-127	-19	-181	14	-56	-170	
19)	63	69	75	81	87	93	99	105	111	117	131	131	131	131	131	19	137	141	146	151	161	81
	-182	-256	30	-43	-117	-190	95	22	-52	-123	-37	-271	-171	-58	47	-202	-94	14	-146	51	-61	

ED

81 89 97 105 113 121 129 137 144 157 159 161 163 165 167 169 171 173 80
 -61 -170 80 -27 -137 -243 3 -95 -222 -117 -46 28 101 -184 -111 -37 36 -250 -6
 139 147 155 163 171 179 187 195 202 116 119 120 122 124 126 128 130 132 134
 17 -90 -199 52 -57 -163 -277 -16 -143 130 -157 -83 -9 63 -222 -148 -75 -1 -287
 22 141 149 157 165 173 181 189 197 111 113 115 117 119 121 123 125 127 129
 -180 -19 -128 -236 13 -92 -205 -305 -72 -157 -86 -11 61 -224 -151 -77 -3 -290 -216
 133 24 143 151 159 167 175 183 190 104 107 109 111 113 115 117 119 121 123
 -19 -215 -53 -161 -271 -17 -131 -230 -357 -83 -11 63 -223 -149 -76 -2 -289 -215 -141
 133 135 26 145 153 161 169 177 185 98 101 103 105 107 109 111 113 115 117
 -128 -53 -250 -88 -198 -304 -58 -157 -284 -9 61 -223 -150 -76 -3 -289 -216 -142 -68
 133 135 137 28 147 155 163 171 179 92 95 97 99 101 103 105 107 109 111
 -236 -161 -88 -285 -124 -230 -344 -83 -210 63 -224 -149 -76 -2 -289 -215 -142 -68 -354
 133 135 137 139 30 149 157 165 173 86 89 91 93 95 97 99 101 103 105
 13 -271 -198 -124 -320 -157 -270 -369 -136 -222 -151 -76 -3 -289 -215 -142 -68 -355 -281
 133 135 137 139 141 32 151 159 167 80 83 85 87 89 91 93 95 97 99
 -92 -17 -304 -230 -157 -355 -196 -296 -423 -148 -77 -2 -289 -215 -142 -68 -354 -281 -207
 133 135 137 139 141 143 34 153 161 74 77 79 81 83 85 87 89 91 93
 -205 -131 -58 -344 -270 -196 -390 -222 -349 -75 -3 -289 -215 -142 -68 -354 -281 -207 -494
 133 135 137 139 141 143 145 36 155 68 71 73 75 77 79 81 83 85 87
 -305 -230 -157 -83 -369 -296 -222 -425 -275 -1 -290 -215 -142 -68 -355 -281 -207 -494 -420
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 -72 -357 -284 -210 -136 -423 -349 -275 -460 -287 -216 -141 -68 -354 -281 -207 -494 -420 -346
 119 120 122 124 126 128 130 132 134 20 139 147 155 163 171 179 187 195 202
 -157 -83 -9 63 -222 -148 -75 -1 -287 -145 17 -90 -199 52 -57 -163 -277 -16 -143
 113 115 117 119 121 123 125 127 129 131 22 141 149 157 165 173 181 189 197
 -86 -11 61 -224 -151 -77 -3 -290 -216 17 -180 -19 -128 -236 13 -92 -205 -305 -72
 107 109 111 113 115 117 119 121 123 131 133 24 143 151 159 167 175 183 190
 -11 63 -223 -149 -76 -2 -289 -215 -141 -90 -19 -215 -53 -161 -271 -17 -131 -230 -357
 101 103 105 107 109 111 113 115 117 131 133 135 26 145 153 161 169 177 185
 61 -223 -150 -76 -3 -289 -216 -142 -68 -199 -128 -53 -250 -88 -198 -304 -58 -157 -284
 95 97 99 101 103 105 107 109 111 131 133 135 137 28 147 155 163 171 179
 -224 -149 -76 -2 -289 -215 -142 -68 -354 52 -236 -161 -88 -285 -124 -230 -344 -83 -210
 89 91 93 95 97 99 101 103 105 131 133 135 137 139 30 149 157 165 173
 -151 -76 -3 -289 -215 -142 -68 -355 -281 -57 13 -271 -198 -124 -320 -157 -270 -369 -136
 83 85 87 89 91 93 95 97 99 131 133 135 137 139 141 143 145 153 161
 -77 -2 -289 -215 -142 -68 -354 -281 -207 -163 -92 -17 -304 -230 -157 -355 -196 -296 -423
 77 79 81 83 85 87 89 91 93 131 133 135 137 139 141 143 145 153 161
 -3 -289 -216 -142 -68 -354 -281 -207 -494 -277 -205 -131 -58 -344 -270 -196 -390 -222 -349
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FOLDOUT FRAME

TABLE 10.1-1) CONTI

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22)	-6	-250	36	-37	-111	-184	101	28	-46	-117	-222	-96	3	-243	-137	-27	80	-170	-61	46	
23)	109	0	102	108	114	120	126	132	138	143	64	65	65	65	65	65	65	65	65	1	
24)	-176	-6	-252	33	-39	-113	-187	99	24	-46	-330	-204	-105	7	-245	-136	-27	80	-170	-61	
25)	109	109	0	101	107	113	119	125	132	137	64	65	65	65	65	65	65	65	65	1	
26)	-285	-159	-6	-251	34	-38	-112	-185	99	28	-79	-313	-213	-100	5	-244	-136	-27	80	-170	
27)	109	109	109	109	0	101	108	113	120	125	64	65	65	65	65	65	65	65	65	1	
28)	-394	-268	-168	-6	-252	34	-39	-112	-187	101	-188	-62	-322	-209	-103	6	-245	-136	-27	80	-1
29)	109	109	109	109	0	101	108	113	120	125	64	65	65	65	65	65	65	65	65	1	
30)	-142	-376	-276	-163	-6	-251	34	-38	-113	-184	-296	-170	-70	-317	-211	-101	6	-244	-136	-27	
31)	109	109	109	109	0	102	107	114	119	64	65	65	65	65	65	65	65	65	65	1	
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38)	-210	-444	-345	-232	-125	-376	-267	-159	-6	-250	-364	-239	-139	-386	-279	-170	-61	-313	-204	-95	-1
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45)	64	65	65	65	65	65	65	65	65	65	0	101	107	113	119	125	132	137	143	10	
46)	-79	-313	-213	-100	5	-244	-136	-27	80	-170	-285	-159	-6	-251	34	-38	-112	-185	99	28	-8
47)	64	65	65	65	65	65	65	65	65	65	0	102	108	114	119	126	131	137	143	9	
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53)	64	65	65	65	65	65	65	65	65	65	0	101	108	113	119	125	132	137	143	8	
54)	-152	-386	-286	-173	-67	-317	-209	-100	7	-243	-358	-232	-132	-379	-273	-163	-6	-251	33	-37	-141
55)	64	65	64	65	65	65	65	65	65	65	0	102	108	114	119	126	131	137	143	7	
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1	-249	-11	-133	-255	-377	-140	-262	-380	-160	-224	-143	-141	-363	-126	-247	-371	-133	-251	-390
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1	126	134	142	150	159	166	175	182	192	192	194	196	198	199	81	224	232	239	249
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TABLE 10.1-1 CON

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2)	170	33	175	181	187	193	199	205	212	218	89	95	101	108	114	120	126	132	139	144	
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3)	168	167	31	174	180	186	192	198	205	211	87	93	100	106	112	118	124	130	137	143	
	-445	-307	-370	-273	-357	-81	-165	-250	24	-56	-212	-296	-380	-105	-189	-273	-357	-81	-166	-247	
4)	166	165	166	29	171	177	184	190	196	202	85	92	98	104	110	116	122	128	135	141	
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5)	165	163	164	163	27	170	176	182	188	194	84	90	96	102	108	114	121	127	133	139	
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6)	163	161	162	161	162	25	167	173	180	186	82	88	94	100	106	113	119	125	131	137	
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7)	161	159	160	160	160	159	23	165	172	178	80	86	92	98	105	111	117	123	129	135	
	-62	-284	-165	-43	-280	-159	-218	-120	-205	73	-189	-273	-357	-81	-165	-250	25	-58	-143	-224	
8)	159	157	158	158	158	157	157	21	164	169	78	84	90	96	103	109	115	121	127	133	
	-146	-368	-250	-127	-4	-243	-120	-180	-83	-164	-273	-357	-81	-165	-249	25	-58	-142	-227	51	
9)	157	156	157	156	156	156	156	156	19	161	76	83	89	95	101	107	113	119	126	132	
	-231	-93	24	-212	-89	31	-205	-83	-142	-42	-358	-82	-166	-250	25	-59	-143	-227	47	-33	
10)	155	154	155	154	154	154	154	153	153	17	74	80	87	93	99	105	111	117	124	129	
	-312	-174	-56	66	-170	-49	73	-164	-42	-104	-79	-163	-247	27	-56	-140	-224	51	-33	-115	
11)	91	97	103	109	116	122	128	134	140	146	35	178	184	190	197	203	209	215	221	227	
	-404	-488	-212	-296	-380	-105	-189	-273	-358	-79	-446	-361	-445	-169	-253	-338	-62	-146	-231	-312	
12)	89	95	101	108	114	120	126	132	139	144	170	33	175	181	187	193	199	205	212	218	
	-488	-212	-296	-380	-105	-189	-273	-357	-82	-163	-361	-408	-307	-391	-115	-200	-284	-368	-93	-174	
13)	87	93	100	106	112	118	124	130	137	143	168	167	31	174	180	186	192	198	205	211	
	-212	-296	-380	-105	-189	-273	-357	-81	-166	-247	-445	-307	-370	-273	-357	-81	-165	-250	24	-56	
14)	85	92	98	104	110	116	122	128	135	141	166	165	166	29	171	177	184	190	196	202	
	-296	-380	-105	-189	-273	-357	-81	-165	-250	27	-169	-391	-273	-332	-235	-319	-43	-127	-212	66	
15)	84	90	96	102	108	114	121	127	133	139	165	163	164	163	27	170	176	182	188	194	
	-380	-105	-189	-273	-357	-81	-165	-249	25	-56	-253	-115	-357	-235	-294	-196	-280	-4	-89	-170	
16)	82	88	94	100	106	113	119	125	131	137	163	161	162	161	162	25	167	173	180	186	
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17)	80	86	92	98	105	111	117	123	129	135	161	159	160	160	159	23	165	172	178		
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18)	78	84	90	96	103	109	115	121	127	133	159	157	158	158	158	158	157	157	21	164	169
	-273	-357	-81	-165	-249	25	-58	-142	-227	51	-146	-368	-250	-127	-4	-243	-120	-180	-83	-164	-7
19)	76	83	89	95	101	107	113	119	126	132	157	156	157	156	156	156	156	156	156	156	156
	-358	-82	-166	-250	25	-59	-143	-227	47	-33	-231	-93	24	-212	-89	31	-205	-83	-142	-42	-1
20)	74	80	87	93	99	105	111	117	124	129	155	154	155	154	154	154	154	154	153	153	17
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 287 -202 -118 -394 -310 -226 -142 -417 -333 -331 -249 -164 -80 -356 -272 -369 -310 -428 -207
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TABLE 10.1-1) CONTINUED

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	-375	-141	-143	-227	-311	-35	-119	-204	70	-10	-145	-367	-249	-126	-3	-242	-119	2	-235	-113			
23)	137	135	1	127	134	140	146	152	158	164	80	78	79	78	78	78	78	78	78	78	77	1	
	-138	-360	-141	-142	-226	-310	-34	-119	-204	74	-267	-129	-11	-248	-125	-4	-241	-119	2	-235	-2		
24)	137	135	136	1	127	134	140	146	152	158	80	78	79	78	78	78	78	78	78	78	78	1	
	-260	-122	-363	-141	-142	-226	-310	-34	-119	-201	-389	-251	-133	-10	-247	-126	-3	-241	-119	2			
25)	137	135	136	136	1	127	134	140	146	152	80	78	79	78	79	78	78	78	78	78	78	1	
	-382	-244	-126	-364	-141	-142	-226	-310	-35	-117	-152	-374	-255	-133	-10	-249	-126	-4	-242	-120	-1		
26)	137	136	137	136	136	1	127	134	140	146	80	79	80	79	79	79	78	78	78	78	78	1	
	-144	-366	-247	-125	-362	-141	-142	-226	-311	-32	-273	-135	-377	-254	-131	-10	-247	-125	-3	-241	-20		
27)	137	136	137	136	136	136	1	127	134	140	80	78	79	79	79	78	78	78	78	78	78	1	
	-267	-129	-371	-248	-125	-364	-141	-142	-227	-308	-396	-258	-140	-378	-255	-133	-10	-249	-126	-4	-3		
28)	138	136	137	137	137	136	136	1	128	133	81	79	80	79	80	79	79	79	79	79	79	1	
	-389	-251	-133	-371	-248	-126	-364	-141	-143	-224	-159	-380	-262	-140	-377	-255	-133	-11	-249	-126	-1		
29)	137	135	136	136	136	135	135	135	1	127	80	78	79	78	78	78	78	78	78	78	1		
	-507	-369	-251	-128	-365	-244	-121	-359	-141	-140	-275	-499	-380	-258	-135	-373	-251	-129	-367	-244	-2		
30)	139	137	138	137	137	137	137	137	137	137	1	81	80	81	80	80	80	80	80	79	79	1	
	-286	-508	-390	-268	-145	-383	-261	-139	-376	-141	-417	-276	-160	-397	-274	-152	-390	-268	-146	-24	-3		
31)	79	78	79	78	78	78	78	78	77	77	77	77	1	127	133	140	146	152	158	164	171	176	1
	-23	-245	-126	-4	-241	-120	2	-235	-113	8	-141	-140	-224	-308	-32	-117	-201	74	-10	-91	-1		
32)	79	78	79	78	78	78	78	78	77	77	137	1	128	134	140	146	152	158	165	171	1		
	-145	-367	-249	-126	-3	-242	-119	2	-235	-113	-375	-141	-143	-227	-311	-35	-119	-204	70	-10			
33)	80	78	79	78	78	78	78	78	78	78	77	137	135	1	127	134	140	146	152	158	164	1	
	-267	-129	-11	-248	-125	-4	-241	-119	2	-235	-138	-360	-141	-142	-226	-310	-34	-119	-204	74			
34)	80	78	79	78	78	78	78	78	78	78	78	137	135	136	1	127	134	140	146	152	158	1	
	-389	-251	-133	-10	-247	-126	-3	-241	-119	2	-260	-122	-363	-141	-142	-226	-310	-34	-119	-201	-2		
35)	80	78	79	78	79	78	78	78	78	78	78	137	135	136	1	127	134	140	146	152	158	1	
	-152	-374	-255	-133	-10	-249	-126	-4	-242	-120	-382	-244	-126	-364	-141	-142	-226	-310	-35	-117	-1		
36)	80	79	80	79	79	79	78	78	78	78	78	137	136	137	1	127	134	140	146	152	158	1	
	-273	-135	-377	-254	-131	-10	-247	-125	-3	-241	-144	-366	-247	-125	-362	-141	-142	-226	-311	-32	-1		
37)	80	78	79	79	79	78	78	78	78	78	78	137	136	137	1	127	134	140	146	152	158	1	
	-396	-258	-140	-378	-255	-133	-10	-249	-126	-4	-267	-129	-371	-248	-125	-364	-141	-142	-227	-308			
38)	81	79	80	79	80	79	79	79	79	79	138	136	137	1	127	136	140	146	152	158	1		
	-159	-380	-262	-140	-377	-255	-133	-11	-249	-126	-389	-251	-133	-371	-248	-126	-364	-141	-143	-224	-2		
39)	80	78	79	78	78	78	78	78	78	78	137	135	136	1	127	134	140	146	152	158	1		
	-275	-499	-380	-258	-135	-373	-251	-129	-367	-244	-507	-369	-251	-128	-365	-244	-121	-359	-141	-140	-2		
40)	81	80	81	80	80	80	80	80	79	79	139	137	138	1	127	137	140	146	152	158	1		
	-417	-276	-160	-397	-274	-152	-390	-268	-146	-24	-286	-508	-390	-268	-145	-383	-261	-139	-376	-141	-1		

Z.

FOLDOUT FRAME

ED

22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
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-72	-209	-345	-122	-259	-396	-169	-310	-454	-113	-250	-387	-163	-300	-436	-215	-347	-487	-276
84	179	188	196	204	213	221	229	240	128	137	145	154	162	170	179	187	195	205
-285	-65	-202	-338	-115	-253	-386	-527	-310	-331	-107	-244	-380	-157	-294	-431	-205	-345	-488
159	84	180	189	197	205	214	221	232	121	129	138	146	154	163	171	180	187	198
-257	-285	-62	-198	-335	-113	-246	-386	-170	-190	-327	-103	-240	-376	-153	-291	-424	-205	-348
157	159	84	180	188	197	205	213	224	112	121	129	138	146	154	163	171	179	190
6	-256	-285	-65	-201	-339	-112	-253	-397	-57	-193	-330	-107	-243	-380	-157	-291	-431	-215
156	157	159	84	180	188	197	204	215	104	112	121	129	137	146	154	163	170	181
-88	7	-256	-285	-64	-202	-335	-115	-259	-279	-56	-192	-329	-105	-242	-380	-153	-294	-437
154	155	157	159	84	180	189	196	207	96	104	112	121	129	137	146	154	162	173
-184	-88	7	-256	-285	-65	-198	-339	-122	-142	-279	-56	-192	-329	-105	-243	-376	-157	-300
153	154	156	157	159	84	180	188	198	87	96	104	112	121	129	138	146	153	164
-279	-183	-87	8	-256	-285	-62	-202	-346	-6	-143	-279	-56	-192	-329	-107	-240	-381	-164
151	152	154	155	157	159	84	179	190	79	87	96	104	112	121	129	138	145	156
-15	-279	-183	-88	7	-256	-285	-66	-209	-229	-6	-142	-279	-56	-192	-330	-103	-244	-387
149	151	153	154	156	157	159	84	182	70	79	87	96	104	112	121	129	137	148
-112	-15	-279	-184	-88	6	-257	-285	-73	-93	-229	-6	-143	-279	-56	-193	-326	-107	-251
148	149	151	152	154	155	157	159	84	62	70	79	87	96	104	112	121	128	139
-203	-106	-10	-275	-179	-84	11	-253	-285	43	-93	-229	-6	-142	-279	-57	-190	-331	-114
147	156	164	173	181	189	198	205	216	84	182	190	198	207	215	224	232	239	250
-250	-387	-163	-300	-436	-215	-347	-487	-276	-285	-72	-209	-345	-122	-259	-396	-169	-310	-454
137	145	154	162	170	179	187	195	205	159	84	179	188	196	204	213	221	229	240
-107	-244	-380	-157	-294	-431	-205	-345	-488	-253	-285	-65	-202	-338	-115	-253	-386	-527	-310
129	138	146	154	163	171	180	187	198	157	159	84	180	189	197	205	214	221	232
-327	-103	-240	-376	-153	-291	-424	-205	-348	11	-257	-285	-62	-198	-335	-113	-246	-386	-170
121	129	138	146	154	163	171	179	190	156	157	159	84	180	188	197	205	213	224
-193	-330	-107	-243	-380	-157	-291	-431	-215	-84	6	-256	-285	-65	-201	-339	-112	-253	-397
112	121	129	137	146	154	163	170	181	154	156	157	159	84	180	188	197	204	215
-56	-192	-329	-105	-242	-380	-153	-294	-437	-180	-88	7	-256	-285	-64	-202	-335	-115	-259
104	112	121	129	137	146	154	162	173	152	154	155	157	159	84	180	189	196	207
-279	-56	-192	-329	-105	-243	-376	-157	-300	-275	-184	-88	7	-256	-285	-65	-198	-339	-122
96	104	112	121	129	138	146	153	164	151	153	154	156	157	159	84	180	188	198
-143	-279	-56	-192	-329	-107	-240	-381	-164	-11	-279	-183	-87	8	-256	-285	-62	-202	-346
87	96	104	112	121	129	138	145	156	149	151	152	154	155	157	159	84	179	190
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-229	-6	-143	-279	-56	-193	-326	-107	-251	-203	-112	-15	-279	-184	-88	6	-257	-285	-73
70	79	87	96	104	112	121	128	139	146	148	149	151	152	154	155	157	159	84
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FOLDOUT FRAME

TABLE 10.1-1) CON

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1)	33	134	140	147	153	159	166	172	179	185	70	76	82	89	95	102	108	114	121	127
	-462	-331	-426	-162	-258	-353	-89	-185	-281	-12	-423	-518	-254	-349	-445	-181	-276	-372	-109	-200
2)	126	31	130	136	142	149	155	161	168	174	68	74	81	87	93	100	106	113	119	125
	-331	-421	-283	-379	-115	-210	-306	-42	-138	-229	-518	-254	-350	-445	-181	-277	-372	-108	-204	-295
3)	124	122	29	128	135	141	148	154	161	167	66	73	79	85	92	98	105	111	118	124
	-426	-283	-380	-239	-334	-70	-165	-261	1	-89	-254	-350	-445	-181	-276	-372	-107	-203	-300	-31
4)	123	120	120	27	126	133	139	145	152	158	65	71	77	84	90	97	103	109	116	122
	-162	-379	-239	-339	-201	-297	-32	-128	-224	44	-349	-445	-181	-276	-372	-108	-203	-299	-35	-127
5)	121	118	119	118	25	124	131	137	144	150	63	69	76	82	89	95	101	108	114	121
	-258	-115	-334	-201	-298	-159	-254	9	-87	-178	-445	-181	-276	-372	-108	-203	-299	-35	-131	-222
6)	119	117	117	117	116	23	122	129	135	142	62	68	74	81	87	93	100	106	113	119
	-353	-210	-70	-297	-159	-257	-117	-214	49	-41	-181	-277	-372	-108	-203	-299	-34	-130	-227	41
7)	118	115	116	115	115	114	21	120	127	133	60	66	73	79	85	92	98	104	111	117
	-89	-306	-165	-32	-254	-117	-216	-77	-174	94	-276	-372	-107	-203	-299	-34	-129	-226	37	-53
8)	116	113	114	113	113	113	112	19	119	125	58	65	71	77	84	90	96	103	109	116
	-185	-42	-261	-128	9	-214	-77	-175	-37	-128	-372	-108	-203	-299	-35	-130	-226	37	-58	-149
9)	115	112	113	112	112	111	111	111	17	116	57	63	70	76	82	89	95	101	108	114
	-281	-138	1	-224	-87	49	-174	-37	-134	8	-109	-204	-300	-35	-131	-227	37	-58	-155	114
10)	113	110	111	110	110	110	109	109	108	8	15	55	61	68	74	81	87	93	100	106
	-12	-229	-89	44	-178	-41	94	-128	8	-93	-200	-295	-31	-127	-222	41	-53	-149	114	22
11)	70	76	82	89	95	102	108	114	121	127	33	134	140	147	153	159	166	172	179	185
	-423	-518	-254	-349	-445	-181	-276	-372	-109	-200	-462	-331	-426	-162	-258	-353	-89	-185	-281	-12
12)	68	74	81	87	93	100	106	113	119	125	126	31	130	136	142	149	155	161	168	174
	-518	-254	-350	-445	-181	-277	-372	-108	-204	-295	-331	-421	-283	-379	-115	-210	-306	-42	-138	-229
13)	66	73	79	85	92	98	105	111	118	124	124	122	29	128	135	141	148	154	161	167
	-254	-350	-445	-181	-276	-372	-107	-203	-300	-31	-426	-283	-380	-239	-334	-70	-165	-261	1	-89
14)	65	71	77	84	90	97	103	109	116	122	123	120	120	27	126	133	139	145	152	158
	-349	-445	-181	-276	-372	-108	-203	-299	-35	-127	-162	-379	-239	-339	-201	-297	-32	-128	-224	44
15)	63	69	76	82	89	95	101	108	114	121	121	118	119	118	25	124	131	137	144	150
	-445	-181	-276	-372	-108	-203	-299	-35	-131	-222	-258	-115	-334	-201	-298	-159	-254	9	-87	-178
16)	62	68	74	81	87	93	100	106	113	119	119	117	117	117	116	23	122	129	135	142
	-181	-277	-372	-108	-203	-299	-34	-130	-227	41	-353	-210	-70	-297	-159	-257	-117	-214	49	-41
17)	60	66	73	79	85	92	98	104	111	117	118	115	116	115	115	114	21	120	127	133
	-276	-372	-107	-203	-299	-34	-129	-226	37	-53	-89	-306	-165	-32	-254	-117	-216	-77	-174	94
18)	58	65	71	77	84	90	96	103	109	116	116	113	114	113	113	112	19	119	125	
	-372	-108	-203	-299	-35	-130	-226	37	-58	-149	-185	-42	-261	-128	9	-214	-77	-175	-37	-128
19)	57	63	70	76	82	89	95	101	108	114	115	112	113	112	111	111	111	17	116	
	-109	-204	-300	-35	-131	-227	37	-58	-155	114	-281	-138	1	-224	-87	49	-174	-37	-134	8
20)	55	61	68	74	81	87	93	100	106	112	113	110	111	110	110	109	109	108	105	
	-200	-295	-31	-127	-222	41	-53	-149	114	22	-12	-229	-89	44	-178	-41	94	-128	8	-93

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FOLDOUT FRAME

118 127 135 143 152 160 3 169 176 187 114 116 118 119 121 122 124 126 127 129
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 20 120 129 137 146 154 162 170 181 108 110 111 113 115 116 118 120 121 123
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 -77 -213 -117 -253 -30 -168 -301 -82 -225 -189 -98 -1 -265 -170 -74 -339 -243 -148 -412
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 113 115 116 26 126 135 143 151 161 89 91 92 94 95 97 99 100 102 103
 9 -253 -157 -295 -199 -336 -109 -250 -394 1 -267 -170 -74 -339 -243 -147 -412 -316 -221
 114 115 117 118 28 128 137 144 155 82 84 86 87 89 91 92 94 95 97
 126 -30 -294 -199 -336 -241 -374 -155 -298 -262 -171 -74 -338 -243 -147 -412 -316 -221 -485
 114 115 117 119 120 30 130 138 149 76 78 79 81 83 84 86 87 89 91
 264 -168 -72 -336 -241 -377 -278 -419 -202 -167 -75 -339 -243 -147 -412 -316 -221 -485 -389
 114 116 118 119 121 122 32 131 142 70 72 73 75 76 78 79 81 83 84
 -37 -301 -205 -109 -374 -278 -418 -323 -467 -71 -340 -243 -147 -412 -316 -221 -485 -389 -294
 114 115 117 119 120 122 123 34 136 63 65 66 68 70 71 73 75 76 78
 -178 -82 -346 -250 -155 -419 -323 -459 -371 -335 -244 -148 -411 -316 -221 -485 -389 -294 -558
 117 118 120 121 123 125 126 128 36 57 59 60 62 63 65 67 68 70 71
 321 -225 -129 -394 -298 -202 -467 -371 -500 -240 -148 -412 -316 -221 -485 -389 -294 -558 -462
 116 118 119 121 122 124 126 127 129 18 118 127 135 143 152 160 169 176 187
 74 -189 93 1 -262 -167 -71 -335 -240 -131 -31 -168 54 -81 -218 3 -129 -269 -53
 110 111 113 115 116 118 120 121 123 110 20 120 129 137 146 154 162 170 181
 -194 -98 -2 -267 -171 -75 -340 -244 -148 -31 -172 -77 -213 9 -126 -264 -37 -178 -321
 103 105 106 108 110 111 113 114 116 111 112 22 122 131 139 147 156 163 174
 -98 -1 -265 -170 -74 -339 -243 -148 -412 -168 -77 -213 -117 -253 -30 -168 -301 -82 -225
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 -2 -265 -169 -74 -338 -243 -147 -411 -316 54 -213 -117 -254 -157 -294 -72 -205 -346 -129
 91 92 94 95 97 99 100 102 103 111 113 115 116 26 126 135 143 151 161
 -267 -170 -74 -339 -243 -147 -412 -316 -221 -81 9 -253 -157 -295 -199 -336 -109 -250 -394
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 -75 -339 -243 -147 -412 -316 -221 -485 -389 3 -264 -168 -72 -336 -241 -377 -278 -419 -202
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 340 -243 -147 -412 -316 -221 -485 -389 -294 -129 -37 -301 -205 -109 -374 -278 -418 -323 -467
 65 66 68 70 71 73 75 76 78 112 114 115 117 119 120 122 123 34 136
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FOLDOUT FRAME

TABLE 10.1-1) CONT1

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23)	94	91	4	87	93	99	106	112	119	125	60	57	58	57	57	56	56	55	55	55	11
24)	94	92	92	4	87	93	100	106	113	119	60	58	58	58	57	57	56	56	56	55	11
25)	95	92	93	92	4	87	93	99	106	112	61	58	58	58	57	57	56	56	56	56	11
26)	95	92	93	92	92	4	87	93	100	106	61	58	59	58	58	57	57	56	56	56	11
27)	96	93	93	93	92	92	4	87	93	99	61	59	59	59	58	58	58	57	57	56	11
28)	96	93	94	93	93	93	92	4	87	93	62	59	60	59	59	58	58	57	57	57	11
29)	95	93	93	93	92	92	92	92	91	4	87	61	59	59	59	58	58	57	57	56	11
30)	98	96	96	96	95	95	94	94	94	4	64	61	62	62	61	61	60	60	60	59	11
31)	59	56	57	56	56	56	55	55	54	54	4	87	93	100	106	112	119	125	132	138	11
32)	59	57	57	57	56	56	56	55	55	54	94	4	87	93	100	106	113	119	125	132	11
33)	60	57	58	57	57	56	56	56	55	55	94	91	4	87	93	99	106	112	119	125	11
34)	60	58	58	58	57	57	56	56	56	55	94	92	92	92	4	87	93	100	106	113	119
35)	61	58	58	58	57	57	57	56	56	56	95	92	93	92	4	87	93	99	106	112	-
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144	210	218	226	234	242	250	258	266	139	80	152	160	168	176	184	192	200	208
-202	-153	-260	-369	-118	-224	-339	-435	-299	-103	-7	-314	-63	-171	-281	-387	-140	-240	-366
188	144	210	218	226	234	242	250	258	128	139	80	152	160	168	176	184	192	200
-255	-209	-164	-273	-382	-128	-243	-338	-473	6	-114	-6	-323	-71	-180	-287	-400	-139	-265
186	187	144	210	218	226	234	242	250	121	128	139	80	152	160	168	176	184	192
31	-253	-206	-158	-268	-373	-128	-224	-358	-244	10	-108	-6	-318	-68	-174	-287	-387	-153
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180	182	184	186	188	144	210	218	226	97	105	112	121	128	139	80	152	160	168
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97	-186	-113	-40	33	-253	-209	-152	-287	-170	81	-27	-135	-246	8	-108	-6	-313	-80
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173	175	177	179	181	183	185	187	144	73	81	89	97	105	112	121	128	139	80
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152	160	168	176	184	192	200	208	215	144	210	218	226	234	242	250	258	266	273
-331	-79	-188	-296	-406	-152	-265	-365	-490	-217	-174	-286	-393	-142	-252	-357	-472	-208	-341
80	152	160	168	176	184	192	200	208	187	144	210	218	226	234	242	250	258	266
-7	-314	-63	-171	-281	-387	-140	-240	-366	-252	-202	-153	-260	-369	-118	-224	-339	-435	-209
139	80	152	160	168	176	184	192	200	185	188	144	210	218	226	234	242	250	258
-114	-6	-323	-71	-180	-287	-400	-139	-265	35	-255	-209	-164	-273	-382	-128	-243	-338	-473
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121	128	139	80	152	160	168	176	184	181	184	186	188	144	210	218	226	234	242
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97	105	112	121	128	139	80	152	160	175	178	179	182	183	186	187	144	210	218
81	-27	-135	-246	8	-108	-6	-313	-80	27	97	-186	-113	-40	33	-253	-209	-152	-287
89	97	105	112	121	128	139	80	152	173	176	178	180	182	184	186	188	144	210
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TABLE 10.2-1) PREDICTED PERFORMANCE OF THE 10

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	-387	-404	-174	-247	-321	-34	-109	-182	-256	31	-231	-102	-364	-84	-155	-230	-303	-17	-91	-163
3)	75	80	31	92	99	105	111	117	123	128	137	149	87	162	161	170	174	181	187	192
	-459	-174	-348	-321	-34	-108	-182	-255	30	-41	-312	-364	-248	-158	-239	-309	-25	-97	-172	-243
4)	73	79	84	29	96	103	109	115	121	126	138	141	154	91	165	165	174	178	185	190
	-173	-247	-321	-325	-109	-181	-256	31	-43	-115	-383	-84	-158	-36	-302	-22	-93	-168	-242	45
5)	71	77	83	88	27	100	107	113	119	124	134	142	145	157	95	169	169	177	182	188
	-247	-321	-34	-109	-284	-256	30	-42	-117	-188	-98	-155	-239	-302	-183	-89	-171	-240	41	-27
6)	69	75	81	87	92	25	104	110	117	122	133	138	146	149	161	99	173	173	182	186
	-320	-34	-108	-181	-256	-252	-43	-115	-191	97	-171	-230	-309	-22	-89	29	-239	41	-30	-103
7)	67	73	79	85	91	96	23	109	115	121	130	137	142	150	153	165	103	177	177	185
	-34	-109	-182	-256	30	-43	-215	-190	95	23	-245	-303	-25	-93	-171	-239	-118	-19	-104	-171
8)	65	71	77	83	89	94	101	21	112	118	128	134	141	146	153	157	169	107	181	180
	-107	-182	-255	31	-42	-115	-190	-181	21	-48	-318	-17	-97	-168	-240	41	-19	95	-179	105
9)	63	69	75	81	87	93	99	104	19	117	127	133	139	145	150	158	161	173	111	185
	-182	-256	30	-43	-117	-191	95	21	-146	-124	-33	-91	-172	-242	41	-30	-104	-179	-54	60
10)	60	66	72	78	84	90	97	102	109	17	124	130	136	142	148	154	161	164	177	114
	-253	31	-41	-115	-188	97	23	-48	-124	-111	-104	-163	-243	45	-27	-103	-171	105	60	163
11)	79	154	153	162	166	173	178	184	191	196	36	84	91	97	103	109	115	121	127	132
	-313	-231	-312	-383	-98	-171	-245	-318	-33	-104	-393	-387	-459	-173	-247	-320	-34	-107	-182	-253
12)	146	83	157	157	166	170	177	182	189	194	76	32	88	95	101	107	113	119	125	130
	-231	-102	-364	-84	-155	-230	-303	-17	-91	-163	-387	-404	-174	-247	-321	-34	-109	-182	-256	31
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14)	138	141	154	91	165	165	174	178	185	190	73	79	84	29	96	103	109	115	121	126
	-383	-84	-158	-36	-302	-22	-93	-168	-242	45	-173	-247	-321	-325	-109	-181	-256	31	-43	-115
15)	134	142	145	157	95	169	169	177	182	188	71	77	83	88	27	100	107	113	119	124
	-98	-155	-239	-302	-183	-89	-171	-240	41	-27	-247	-321	-34	-109	-284	-256	30	-42	-117	-188
16)	133	138	146	149	161	99	173	173	182	186	69	75	81	87	92	25	104	110	117	122
	-171	-230	-309	-22	-89	29	-239	41	-30	-103	-320	-34	-108	-181	-256	-252	-43	-115	-191	97
17)	130	137	142	150	153	165	103	177	177	185	67	73	79	85	91	96	23	109	115	121
	-245	-303	-25	-93	-171	-239	-118	-19	-104	-171	-34	-109	-182	-256	30	-43	-215	-190	95	23
18)	128	134	141	146	153	157	169	107	181	180	65	71	77	83	89	94	101	21	112	118
	-318	-17	-97	-168	-240	41	-19	95	-179	105	-107	-182	-255	31	-42	-115	-190	-181	21	-48
19)	127	133	139	145	150	158	161	173	111	185	63	69	75	81	87	93	99	104	19	117
	-33	-91	-172	-242	41	-30	-104	-179	-54	60	-182	-256	30	-43	-117	-191	95	21	-146	-124

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 -61 -170 80 -27 -136 -244 6 -102 -6 -117 -47 27 100 -185 -111 -38 36 -252 -218
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 58 -83 -10 63 -222 -149 -75 -2 -287 129 24 71 -205 -137 -62 11 -278 -196 -139
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 51 -76 -3 -290 -318 -143 -68 -355 -281 -62 7 -275 -205 -123 -217 -336 -273 -188 -133
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 77 -3 -290 -215 -143 -359 -355 -281 -207 11 -276 -202 -127 -56 -336 -70 -192 -118 -417
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 16 -141 -68 -354 -281 -207 -493 -421 -425 -139 -68 -353 -280 -206 -133 -417 -347 -266 -347
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 88 -213 -138 -64 7 -276 -207 -125 -68 -158 -180 -12 61 -225 -151 -77 -4 -290 -216
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 5 -50 -337 -264 -188 -118 -398 -136 -266 -2 -290 -216 -143 -69 -355 -281 -208 -439 -421
 9 130 132 135 136 139 139 147 81 62 65 66 69 71 73 74 77 78 38
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TABLE 10.2-1) CONTIN

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21)	-104	-163	-243	45	-27	-103	-171	105	60	163	-253	31	-41	-115	-188	97	23	-48	-124	-111	4	
21)	64	115	121	127	133	139	145	151	157	163	0	67	64	65	64	65	65	65	65	65	65	2
22)	-217	-252	35	-38	-111	-185	100	27	-47	-117	-6	-103	6	-244	-136	-27	80	-170	-61	46	-14	
22)	122	64	116	122	128	134	140	146	152	157	64	0	67	64	65	64	65	65	65	65	65	11
23)	-174	-202	-255	31	-42	-115	-189	97	21	-47	-331	-7	-114	10	-247	-135	-28	81	-170	-61	-15	
23)	122	122	64	115	122	127	134	139	146	151	64	64	0	67	64	65	64	65	65	65	10	
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24)	122	122	122	64	116	122	128	134	140	145	64	64	64	0	67	64	65	64	65	65	9	
25)	-393	-260	-164	-206	-254	32	-41	-113	-189	100	-188	-63	-323	-6	-112	9	-246	-135	-28	80	-1	
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26)	-142	-369	-273	-158	-207	-254	32	-40	-115	-185	-296	-171	-71	-318	-6	-109	9	-246	-135	-27	6	
26)	122	122	122	122	122	64	116	122	128	133	64	64	64	64	0	67	64	65	64	65	8	
27)	-252	-118	-382	-268	-162	-207	-254	33	-42	-111	-406	-281	-180	-68	-321	-6	-112	8	-247	-136	-22	
27)	122	122	122	122	122	64	115	122	127	134	139	64	64	64	64	0	67	64	65	64	65	8
28)	-357	-224	-128	-373	-267	-158	-205	-253	31	-38	-152	-387	-287	-174	-67	-318	-6	-108	10	-244	-14	
28)	122	122	122	122	122	122	64	115	122	127	64	64	64	64	64	64	64	64	64	64	7	
29)	-472	-339	-243	-128	-383	-273	-164	-209	-255	-36	-265	-140	-400	-287	-181	-71	-323	-6	-114	6	-7	
29)	122	122	122	122	122	122	122	122	122	122	64	64	64	64	64	64	64	64	64	64	6	
30)	-208	-435	-338	-224	-118	-368	-259	-152	-201	-252	-365	-240	-139	-387	-280	-170	-62	-313	-7	-102	-	
30)	121	122	122	122	122	122	122	122	122	122	64	63	64	64	64	64	64	64	64	64	6	
31)	-341	-209	-473	-358	-253	-143	-394	-287	-175	-218	-490	-366	-266	-153	-406	-297	-189	-80	-331	-6	-28	
31)	0	67	64	65	64	65	65	65	65	65	65	64	115	121	127	133	139	145	151	157	163	
32)	-6	-103	6	-244	-136	-27	80	-170	-61	46	-217	-252	35	-38	-111	-185	100	151	157	163	12	
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7)	80	86	92	98	105	110	23	123	129	135	168	173	180	186	191	201	128	213	215	222	21
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14)	173	177	189	115	201	202	210	216	222	228	85	92	97	29	110	116	122	128	135	141	13
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23)	161	159	89	153	159	165	171	177	184	189	79	78	1	80	78	78	78	78	77	119	
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24)	161	159	160	89	153	159	165	171	178	183	80	78	79	1	81	77	78	78	78	113	
	-288	-145	-388	-36	-170	-253	21	-62	-148	-227	-389	-252	-133	-142	-239	-131	0	-243	-119	2	-262
25)	161	159	161	160	89	153	159	165	172	177	80	78	79	78	1	81	77	78	78	107	
	-411	-267	-150	-28	-36	-170	-253	21	-63	-143	-152	-375	-256	-134	-142	-241	-131	-1	-243	-119	-177
26)	162	159	161	160	160	89	153	159	165	171	80	78	79	79	79	1	81	78	78	101	
	-172	-389	-272	-149	-388	-36	-170	-253	19	-58	-273	-136	-377	-255	-132	-142	-239	-131	0	-243	-93
27)	161	159	161	160	160	160	89	153	159	165	80	78	79	78	79	78	1	80	77	78	
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28)	163	160	162	161	161	161	160	89	153	159	81	79	80	79	79	79	79	1	81	78	
	-419	-274	-158	-395	-272	-150	-28	-36	-171	-250	-159	-381	-263	-141	-378	-256	-133	-142	-240	-132	-285
29)	161	159	160	159	159	159	159	159	88	153	80	78	79	78	79	78	78	1	80	82	
	-172	-392	-274	-152	-388	-267	-145	-383	-33	-167	-275	-500	-381	-259	-136	-374	-252	-130	-142	-237	-201
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31)	1	80	78	78	78	78	78	78	78	77	77	77	89	153	159	165	171	177	183	189	
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32)	79	1	81	77	78	78	78	78	78	77	77	161	88	153	159	165	172	178	184	190	
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33)	79	78	1	80	78	78	78	78	78	77	161	159	89	153	159	165	171	177	184	189	
	-267	-130	-142	-241	-131	-1	-243	-119	2	-235	-167	-383	-36	-170	-253	21	-62	-146	-232	48	-250
34)	80	78	79	1	81	77	78	78	78	78	161	159	160	89	153	159	165	171	178	183	
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35)	80	78	79	78	1	81	77	78	78	78	161	159	161	160	89	153	159	165	172	177	
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	-417	-276	-160	-397	-274	-153	-390	-268	-146	-141	-322	-174	-420	-296	-174	-412	-290	-168	-44	-47	-382

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-20	76	-187	-92	3	-261	-110	-71	-216	-229	-6	-143	-278	-56	-197	-316	-286	-245	-387
170	171	173	174	176	177	179	142	201	70	79	87	96	104	112	121	129	84	148
-117	-20	75	-189	-93	3	-263	-113	-81	-93	-229	-6	-143	-278	-56	-198	-313	-286	-251
168	169	170	172	174	175	177	178	144	62	70	79	87	96	104	112	121	129	84
-206	-109	-12	-277	-182	-86	9	-256	-119	43	-93	-229	-6	-143	-278	-57	-195	-319	-285
147	156	164	173	181	189	198	205	216	144	200	209	218	226	234	243	251	258	270
-250	-387	-164	-300	-437	-215	-347	-488	-275	-119	-80	-215	-354	-128	-266	-405	-176	-318	-469
84	145	154	162	170	179	187	195	205	179	142	198	206	214	223	231	240	247	258
-286	-245	-381	-158	-295	-432	-206	-346	-488	-256	-113	-70	-208	-344	-121	-259	-391	-173	-318
129	84	146	154	163	171	180	187	198	177	179	142	199	207	215	224	233	240	252
-313	-286	-241	-377	-154	-292	-425	-206	-348	9	-263	-110	-66	-202	-339	-117	-249	-392	-177
121	129	84	146	154	163	171	179	190	175	177	178	142	199	207	216	224	231	243
-198	-316	-286	-244	-381	-158	-291	-432	-215	-86	3	-261	-113	-70	-207	-345	-117	-259	-405
112	121	129	84	146	154	163	170	181	174	176	177	178	142	198	207	215	223	234
-56	-197	-316	-286	-243	-381	-154	-295	-437	-182	-93	3	-260	-112	-69	-207	-339	-121	-267
104	112	121	129	84	146	154	162	173	172	174	175	177	178	142	199	207	214	226
-278	-56	-197	-315	-286	-244	-377	-158	-300	-278	-189	-92	4	-261	-112	-70	-202	-345	-130
96	104	112	121	129	84	146	154	164	170	173	174	175	177	178	142	199	206	218
-143	-278	-56	-197	-316	-286	-241	-382	-164	-13	75	-187	-91	4	-260	-113	-66	-209	-354
87	96	104	112	121	129	84	145	156	169	171	172	174	175	177	178	142	198	209
-6	-143	-278	-56	-197	-316	-286	-245	-387	-109	-20	76	-187	-92	3	-261	-110	-71	-216
79	87	96	104	112	121	129	84	148	168	170	171	173	174	176	177	179	142	201
229	-6	-143	-278	-56	-198	-313	-286	-251	-206	-117	-20	75	-189	-93	3	-263	-113	-81
70	79	87	96	104	112	121	129	84	165	168	169	170	172	174	175	177	178	144
-93	-229	-6	-143	-278	-57	-195	-319	-285	64	-206	-109	-12	-277	-182	-86	9	-256	-119

FOLDOUT FRAME

TABLE 10.2-11 CONT

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	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1)	32	76	82	89	95	101	108	114	121	127	75	138	143	148	155	161	168	174	181	187	
	-439	-519	-253	-349	-445	-181	-276	-372	-108	-200	-425	-331	-457	-181	-278	-375	-109	-206	-302	-33	
2)	68	33	80	87	93	100	106	113	119	125	130	80	140	145	151	158	164	171	177	183	
	-519	-426	-350	-445	-181	-277	-372	-108	-205	-296	-331	-258	-156	-284	-368	-104	-201	-296	-33	-124	
3)	66	72	29	85	92	98	105	111	118	124	127	132	85	146	151	156	164	170	176	182	
	-253	-350	-383	-182	-277	-373	-108	-204	-301	-32	-457	-156	-449	-346	-112	-196	-292	-30	-125	-217	
4)	65	71	77	27	90	97	103	109	116	122	124	129	138	90	151	155	161	168	175	181	
	-349	-445	-182	-336	-373	-107	-203	-299	-36	-127	-181	-284	-346	-280	-181	-307	-30	-127	-226	43	
5)	63	69	76	82	26	95	101	107	114	120	123	127	135	143	94	155	160	165	173	179	
	-445	-181	-277	-373	-298	-203	-297	-34	-130	-221	-278	-368	-112	-181	-111	-11	-137	-221	40	-52	-11
6)	61	68	74	81	87	23	99	106	113	119	121	126	132	139	147	99	160	165	170	177	
	-181	-277	-373	-107	-203	-257	-39	-134	-232	37	-375	-104	-196	-307	-11	-303	-204	30	-54	-146	-27
7)	60	66	73	79	85	91	21	105	112	119	120	124	132	137	144	152	104	165	170	175	
	-276	-372	-108	-203	-297	-39	-215	-221	43	-48	-109	-201	-292	-30	-137	-204	-133	-37	-163	116	-1
8)	58	65	71	77	83	90	97	19	107	113	118	123	130	136	141	149	157	109	169	174	
	-372	-108	-204	-299	-34	-134	-221	-175	-54	-144	-206	-296	-30	-127	-221	30	-37	34	-225	13	-105
9)	57	63	70	76	82	89	96	99	17	113	117	121	128	135	141	146	154	161	114	173	168
	-108	-205	-301	-36	-130	-232	43	-54	-134	70	-302	-33	-125	-226	40	-54	-163	-225	-158	-63	-206
10)	55	61	68	74	80	87	95	97	105	15	115	119	126	133	139	145	151	158	118	165	
	-200	-296	-32	-127	-221	37	-48	-144	70	-93	-33	-124	-217	43	-52	-146	116	13	-63	19	64
11)	75	138	143	148	155	161	168	174	181	187	32	76	82	89	95	101	108	114	121	127	8
	-425	-331	-457	-181	-278	-375	-109	-206	-302	-33	-439	-519	-253	-349	-445	-181	-276	-372	-108	-200	-28
12)	130	80	140	145	151	158	164	171	177	183	68	33	80	87	93	100	106	113	119	125	17
	-331	-258	-156	-284	-368	-104	-201	-296	-33	-124	-519	-426	-350	-445	-181	-277	-372	-108	-205	-296	-31
13)	127	132	85	146	151	156	164	170	176	182	66	72	29	85	92	98	105	111	118	124	1
	-457	-156	-449	-346	-112	-196	-292	-30	-125	-217	-253	-350	-383	-182	-277	-373	-108	-204	-301	-32	-1
14)	124	129	138	90	151	155	161	168	175	181	65	71	77	27	90	97	103	109	116	122	1
	-181	-284	-346	-280	-181	-307	-30	-127	-226	43	-349	-445	-182	-336	-373	-107	-203	-299	-36	-127	-1
15)	123	127	135	143	94	155	160	165	173	179	63	69	76	82	26	95	101	107	114	120	
	-278	-368	-112	-181	-111	-11	-137	-221	40	-52	-445	-181	-277	-373	-298	-203	-297	-34	-130	-221	
16)	121	126	132	139	147	99	160	165	170	177	61	68	74	81	87	23	99	106	113	119	
	-375	-104	-196	-307	-11	-303	-204	30	-54	-146	-181	-277	-373	-107	-203	-257	-39	-134	-232	37	
17)	120	124	132	137	144	152	104	165	170	175	60	66	73	79	85	91	21	105	112	119	
	-109	-201	-292	-30	-137	-204	-133	-37	-163	116	-276	-372	-108	-203	-297	-39	-215	-221	43	-48	
18)	118	123	130	136	141	149	157	109	169	174	58	65	71	77	83	90	97	19	107	113	
	-206	-296	-30	-127	-221	30	-37	34	-225	13	-372	-108	-204	-299	-34	-134	-221	-175	-54	-144	
19)	117	121	128	135	141	146	154	161	114	173	57	63	70	76	82	89	96	99	17	113	
	-302	-33	-125	-226	40	-54	-163	-225	-158	-63	-108	-205	-301	-36	-130	-232	43	-54	-134	71	
20)	115	119	126	133	139	145	151	158	165	118	55	61	68	74	80	87	95	97	105	1	
	-33	-124	-217	43	-52	-146	116	13	-63	19	-200	-296	-32	-127	-221	37	-48	-144	70	-9	

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115 115 121 121 122 124 126 127 129 120 175 176 177 179 181 183 184 185 189
 30 -184 -88 -2 -261 -167 -72 -336 -239 -20 -102 -26 76 -186 -92 3 -257 -164 -74
 20 109 114 115 116 118 119 121 123 167 116 171 172 175 176 178 179 183
 -172 -93 4 -271 -170 -75 -340 -244 -148 -102 -198 -265 -203 -94 1 -265 -165 -73 -342
 101 22 107 108 109 111 113 114 116 160 163 110 167 166 167 170 171 172 176
 -93 -214 -261 -174 -74 -339 -244 -148 -412 -26 -265 -5 -77 -9 -261 -167 -70 -336 -246
 98 99 24 101 103 105 106 108 110 153 156 159 106 162 162 163 166 166 170
 4 -261 -254 -79 -337 -243 -148 -412 -316 76 -203 -77 -173 -244 -177 -70 -332 -241 -149
 91 92 93 26 96 99 100 102 103 147 148 150 154 101 157 157 158 160 163
 -271 -174 -79 -296 -243 -147 -413 -317 -220 -186 -94 -9 -244 -343 -51 -347 -236 -144 -416
 84 85 87 88 28 92 94 95 97 141 143 143 146 149 96 153 153 153 157
 -170 -74 -337 -243 -337 -412 -316 -221 -485 -92 1 -261 -177 -51 -151 -220 -152 -407 -318
 78 79 81 83 84 30 87 89 91 135 136 138 139 141 145 92 148 147 150
 -75 -339 -243 -147 -412 -375 -222 -484 -389 3 -265 -167 -70 -347 -220 -320 -385 -324 -221
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 -340 -244 -148 -413 -316 -222 -422 -390 -293 -257 -165 -70 -332 -236 -152 -385 -489 -196 -498
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 -244 -148 -412 -317 -221 -484 -390 -465 -558 -164 -73 -336 -241 -144 -407 -324 -196 -297 -371
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 -148 -412 -316 -220 -485 -389 -293 -558 -477 -74 -342 -246 -149 -416 -318 -221 -498 -371 -465
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 -102 -26 76 -186 -92 3 -257 -164 -74 -131 30 -184 -88 -2 -261 -167 -72 -336 -239
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 -198 -265 -203 -94 1 -265 -165 -73 -342 30 -172 -93 4 -271 -170 -75 -340 -244 -148
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 -265 -5 -77 -9 -261 -167 -70 -336 -246 -184 -93 -214 -261 -174 -74 -339 -244 -148 -412
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 -203 -77 -173 -244 -177 -70 -332 -241 -149 -88 4 -261 -254 -79 -337 -243 -148 -412 -316
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 -94 -9 -244 -343 -51 -347 -236 -144 -416 -2 -271 -174 -79 -296 -243 -147 -413 -317 -220
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 1 -261 -177 -51 -151 -220 -152 -407 -318 -261 -170 -74 -337 -243 -337 -412 -316 -221 -485
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 -265 -167 -70 -347 -220 -320 -385 -324 -221 -167 -75 -339 -243 -147 -412 -375 -222 -484 -389
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 -165 -70 -332 -236 -152 -335 -489 -196 -498 -72 -340 -244 -148 -413 -316 -222 -422 -390 -293
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 -73 -336 -241 -144 -407 -324 -196 -297 -371 -336 -244 -148 -412 -317 -221 -484 -390 -465 -558
 119 120 122 123 125 126 129 132 77 57 59 60 62 63 65 67 68 70 34
 342 -246 -149 -416 -318 -221 -498 -371 -465 -239 -148 -412 -316 -220 -485 -389 -293 -558 -477

TABLE 10.2-1) CONT'D

21)	64	107	113	119	126	132	138	145	152	157	4	57	57	56	56	56	55	55	54	54	54	-1
22)	112	62	107	113	120	126	133	139	146	152	59	4	57	57	56	56	56	55	55	54	54	1
23)	113	110	62	106	113	119	126	132	139	145	60	57	57	56	56	56	55	55	54	54	54	-1
24)	114	110	111	62	106	113	119	126	133	138	60	58	58	4	57	57	56	56	56	55	55	-1
25)	114	110	111	111	62	106	113	119	126	132	61	58	58	4	57	57	56	56	56	56	56	1
26)	114	110	111	111	110	62	106	113	120	126	61	58	59	58	58	4	57	57	56	56	56	1
27)	115	111	112	112	111	111	62	106	113	119	61	59	59	59	58	58	4	57	57	56	56	-1
28)	115	112	113	112	111	111	111	62	107	113	62	59	60	59	59	58	58	4	57	57	57	-1
29)	114	111	112	111	111	110	110	110	62	106	61	59	59	59	58	58	58	57	4	57	57	-1
30)	118	114	116	115	114	114	114	113	113	64	64	61	62	62	61	61	60	60	60	60	4	-1
31)	4	57	57	56	56	56	55	55	54	54	64	107	113	119	126	132	138	145	152	157	1	
32)	59	4	57	57	56	56	56	55	55	54	112	62	107	113	120	126	133	139	146	152	1	
33)	60	57	4	57	57	56	56	56	55	55	113	110	62	106	113	119	126	132	139	145	1	
34)	60	58	58	4	57	57	56	56	56	55	114	110	111	62	106	113	119	126	133	138	1	
35)	61	58	58	58	4	57	57	56	56	56	114	110	111	111	62	106	113	119	126	132	14	
36)	61	58	59	58	58	4	57	57	56	56	114	111	111	111	110	62	106	113	120	126	14	
37)	61	59	59	59	58	58	4	57	57	56	115	111	112	112	111	62	106	113	119	126	13	
38)	62	59	60	59	59	58	58	4	57	57	115	112	113	112	111	111	62	107	113	12	-25	
39)	61	59	59	59	58	58	58	57	4	57	114	111	112	112	111	111	110	62	106	12	-25	
40)	64	61	62	62	61	61	60	60	60	4	118	114	116	115	114	114	113	64	11	-81	-119	-74

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FOLDOUT FRAME

LITHIC GaAs RF SWITCH
WITH BUFFER AMPLIFIERS

22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
147	154	162	170	178	186	194	202	210	208	208	211	216	221	229	233	242	242	152
-332	-72	-184	-290	-400	-147	-258	-362	-480	-73	-180	-284	-396	-137	-260	-343	-149	-175	-264
144	147	154	163	170	178	186	194	202	200	200	204	208	215	218	230	227	136	242
-202	-318	-64	-174	-182	-390	-141	-245	-363	-308	-53	-161	-265	-383	-114	-275	-315	-407	-176
246	144	147	154	163	170	178	186	194	192	192	195	201	204	214	212	120	227	241
-41	-209	-325	-68	-179	-286	-397	-141	-259	-206	-317	-55	-178	-262	-70	-99	-189	-314	-150
245	241	144	147	154	163	170	178	186	185	183	188	190	200	198	104	212	230	233
-117	-93	-206	-322	-66	-176	-286	-390	-148	-98	-196	-316	-42	-209	-240	-332	-99	-274	-344
243	240	243	144	147	154	163	170	178	176	177	177	186	183	88	198	214	218	229
-190	-165	-70	-207	-324	-66	-179	-282	-401	17	-107	-186	2	-23	-115	-240	-70	-114	-261
243	238	242	242	144	147	154	163	170	169	165	173	169	72	183	200	204	215	221
-272	-241	-151	-88	-207	-321	-68	-174	-291	-254	31	-142	-165	-258	-23	-209	-263	-383	-138
241	238	241	242	243	144	147	154	162	158	161	156	56	169	186	190	201	208	216
23	52	-213	-150	-70	-205	-325	-64	-184	-109	61	52	-41	-166	2	-42	-178	-264	-397
240	236	238	238	240	241	144	147	154	151	144	40	156	173	177	188	195	204	211
-77	-32	51	-242	-166	-94	-209	-318	-73	-86	-89	-183	52	-142	-186	-316	-55	-161	-285
241	240	241	242	243	244	246	144	147	135	24	144	161	165	177	183	192	200	208
-107	-75	23	-270	-188	-115	-39	-201	-332	131	32	-89	61	31	-107	-196	-317	-52	-181
235	233	233	233	234	235	236	237	144	8	135	151	158	169	176	185	192	200	208
109	-183	-107	-36	38	-248	-175	-101	-218	-108	131	-86	-110	-255	17	-98	-207	-308	-74
208	211	216	221	229	233	242	242	152	144	147	154	162	170	178	186	194	202	210
-180	-284	-396	-137	-260	-343	-149	-175	-264	-217	-332	-72	-184	-290	-400	-147	-258	-362	-480
200	204	208	215	218	230	227	136	242	237	144	147	154	163	170	178	186	194	202
-53	-161	-265	-383	-114	-275	-315	-407	-176	-100	-202	-318	-64	-174	-282	-390	-141	-245	-363
192	195	201	204	214	212	120	227	241	236	246	144	147	154	163	170	178	186	194
-317	-55	-178	-262	-70	-99	-189	-314	-150	-174	-41	-209	-325	-68	-179	-286	-397	-141	-259
183	188	190	200	198	104	212	230	233	235	245	241	144	147	154	163	170	178	186
-196	-316	-42	-209	-240	-332	-99	-274	-344	-248	-117	-93	-206	-322	-66	-176	-286	-390	-148
177	177	186	183	88	198	214	218	229	234	243	240	243	144	147	154	163	170	178
-107	-136	2	-23	-115	-240	-70	-114	-261	38	-190	-165	-70	-207	-324	-66	-179	-282	-401
165	173	169	72	183	200	204	215	221	233	243	238	242	242	144	147	154	163	170
31	-142	-165	-258	-23	-209	-263	-383	-138	-35	-272	-241	-151	-88	-207	-321	-68	-174	-291
161	156	56	169	186	190	201	208	216	233	241	238	241	242	243	144	147	154	162
61	52	-41	-166	2	-42	-178	-264	-397	-107	23	52	-213	-150	-70	-205	-325	-64	-184
144	40	156	173	177	188	195	204	211	233	240	236	238	238	240	241	144	147	154
-89	-183	52	-142	-186	-316	-55	-161	-285	-183	-77	-32	51	-242	-166	-94	-209	-318	-73

FOLDOUT FRAME

TABLE 10.3-1
PREDICTED PERFORMANCE OF THE 10 X 10 MOF
MATRIX IN A SECOND POSSIBLE BYPASS STATE

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0000001000
0000010000
0001000000
0010000000
0100000000
1000000000

F = 17.50

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1)	35	153	159	165	171	177	182	189	193	197	79	85	91	97	103	109	115	120	124	132	-1
	-426	-241	-315	-388	-103	-174	-251	-320	-37	-110	-312	-386	-100	-173	-247	-320	-35	-107	-183	-254	-1
2)	145	33	151	157	163	169	174	181	185	189	77	83	89	95	101	107	112	117	125	227	2
	-241	-391	-189	-262	-337	-48	-125	-195	-271	, 15	-386	-100	-173	-247	-320	-35	-108	-183	-258	-138	-1
3)	143	143	31	149	155	161	167	173	177	181	75	81	87	93	99	104	108	117	213	225	2
	-315	-189	-356	-162	-237	-309	-25	-95	-172	-244	-100	-173	-247	-320	-35	-107	-183	-256	-143	-212	-1
4)	141	141	141	29	146	153	158	165	169	173	73	79	85	91	96	100	109	203	212	225	2
	-388	-262	-162	-320	-123	-195	-271	17	-58	-132	-173	-247	-320	-35	-108	-183	-257	-142	-217	74	-2
5)	139	139	139	138	27	146	151	158	161	166	71	77	83	88	92	101	194	202	211	224	2
	-103	-337	-237	-123	-287	-90	-167	-236	46	-25	-247	-320	-35	-108	-183	-256	-142	-215	69	0	
6)	137	137	137	137	138	25	141	148	153	156	69	75	80	84	93	185	193	201	211	223	2
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7)	134	134	135	134	135	133	23	144	146	151	67	72	76	85	178	185	193	201	210	223	2
	-251	-125	-25	-271	-167	-53	-220	-21	-101	-166	-35	-108	-183	-257	-142	-216	69	-3	-78	-147	-1
8)	133	133	133	133	134	132	136	21	135	139	64	69	77	171	178	185	193	201	211	223	2
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9)	129	129	129	129	129	129	130	127	17	143	60	69	165	172	179	187	194	203	212	225	2
	-37	-271	-172	-58	46	-200	-101	21	-159	45	-183	-258	-143	-217	69	-4	-78	-151	133	63	1
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	-110	15	-244	-132	-25	83	-166	-60	45	-90	-254	-138	-212	74	0	-72	-147	141	63	7	
11)	79	85	91	97	103	109	115	120	124	132	35	153	159	165	171	177	182	189	193	197	2
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12)	77	83	89	95	101	107	112	117	125	227	145	33	151	157	163	169	174	181	185	189	2
	-386	-100	-173	-247	-320	-35	-108	-183	-258	-138	-241	-391	-189	-262	-337	-48	-125	-195	-271	15	-30
13)	75	81	87	93	99	104	108	117	213	225	143	143	31	149	155	161	167	173	177	181	1
	-100	-173	-247	-320	-35	-107	-183	-256	-143	-212	-315	-189	-356	-162	-237	-309	-25	-172	-244	-2	
14)	73	79	85	91	96	100	109	203	212	225	141	141	141	29	146	153	158	165	169	173	1
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15)	71	77	83	88	92	101	194	202	211	224	139	139	139	138	27	146	151	158	161	166	1
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16)	69	75	80	84	93	185	193	201	211	223	137	137	137	138	25	141	148	153	156	156	1
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17)	67	72	76	85	178	185	193	201	210	223	134	134	135	134	135	133	23	144	146	151	1
	-35	-108	-183	-257	-142	-216	69	-3	-78	-147	-251	-125	-25	-271	-167	-53	-220	-21	-101	-166	-1
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	-107	-183	-256	-142	-215	70	-3	-76	-151	141	-320	-195	-95	17	-236	-126	-21	-173	21	-60	-1

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ED

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 99 -185 -112 -38 35 -251 -177 -292 -217 10 -194 -13 -135 -234 11 -92 -206 -305 -72
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 185 -110 -37 36 -249 -176 -290 -218 -141 -94 -13 -207 -55 -160 -270 -16 -129 -228 -355
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 112 -37 35 -250 -176 -291 -217 -142 -69 -200 -135 -55 -254 -88 -201 -305 -60 -158 -286
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 -38 36 -250 -176 -291 -217 -142 -69 -354 49 -234 -160 -88 -283 -124 -229 -343 -82 -209
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FOLDOUT FRAME

TABLE 10.3-1) CONT

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22)	64	165	172	179	186	193	201	209	219	226	128	128	128	128	128	128	129	126	127	119	0
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24)	59	64	174	181	187	195	201	208	217	219	120	120	120	119	121	117	121	112	0	119	131
25)	-332	-202	-41	-117	-190	-272	23	-77	-107	109	-180	-53	-317	-196	-107	31	61	-89	32	131	-1
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27)	-72	-318	-209	-93	-165	-241	52	-32	-75	-183	-284	-161	-55	-316	-186	-142	52	-183	-89	-86	-
28)	58	58	59	64	171	178	185	190	201	201	112	112	113	110	114	105	0	108	121	126	1
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30)	58	59	58	59	64	170	178	182	194	193	109	111	108	112	103	0	105	117	117	129	1
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35)	-147	-390	-286	-176	-66	-321	-205	-94	-115	-248	-343	-275	-99	-332	-240	-209	-42	-316	-196	-98	-
36)	58	58	58	59	58	64	174	172	106	99	0	100	110	108	113	115	120	128	-207	-	
37)	-258	-141	-397	-286	-179	-68	-325	-209	-39	-175	-149	-315	-189	-99	-70	-263	-178	-55	-317	-207	-
38)	58	58	58	59	58	64	171	178	185	193	190	109	108	107	109	112	115	120	128	-	
39)	-362	-245	-141	-390	-282	-174	-64	-318	-201	-101	-175	-407	-314	-274	-114	-383	-264	-161	-52	-308	-
40)	58	58	58	58	59	58	59	64	165	98	0	99	110	106	111	112	116	120	128	-	
41)	-480	-363	-259	-148	-401	-291	-184	-73	-332	-218	-264	-176	-150	-344	-261	-138	-397	-285	-181	-74	-
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43)	-73	-308	-206	-98	17	-254	-109	-86	131	-108	-217	-100	-174	-248	38	-35	-107	-183	110	30	-
44)	120	120	120	119	121	117	121	112	0	119	59	64	174	181	187	195	201	208	217	219	-
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46)	115	116	115	116	113	117	108	0	112	127	58	59	64	169	176	182	190	196	208	209	-
47)	-284	-161	-55	-316	-186	-142	52	-183	-89	-86	-72	-318	-209	-93	-165	-241	52	-32	-75	-183	-
48)	112	112	113	110	114	105	0	108	121	126	58	58	59	64	171	178	185	190	201	201	-
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50)	109	111	108	112	103	0	105	117	117	129	58	59	58	64	170	178	182	194	193	-	
51)	-137	-383	-262	-209	-23	-258	-166	-142	31	-255	-290	-174	-68	-322	-207	-88	-150	-242	-270	-36	-
52)	109	106	110	102	0	103	114	113	121	128	58	58	59	58	64	171	176	187	186	-	
53)	-260	-114	-70	-240	-115	-23	2	-186	-107	17	-400	-282	-179	-66	-324	-207	-70	-166	-188	38	-
54)	105	110	100	0	102	112	110	116	119	129	58	58	58	59	59	59	64	169	180	179	-
55)	-343	-275	-99	-332	-240	-209	-42	-316	-196	-98	-147	-390	-286	-176	-66	-321	-205	-94	-115	-248	-
56)	106	99	0	100	110	108	113	115	120	128	58	58	58	58	59	59	64	174	172	-	
57)	-149	-315	-189	-99	-70	-263	-178	-55	-317	-207	-258	-141	-397	-286	-179	-68	-325	-209	-39	-175	-
58)	98	0	99	110	106	111	112	116	120	128	58	58	58	58	59	59	64	174	172	-	
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284	287	169	162	168	177	185	193	202	221	214	214	219	227	225	106	239	255	262
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222	224	228	233	242	239	122	254	275	288	285	169	162	169	177	185	194	201	210
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214	214	219	227	225	106	239	255	262	288	284	287	169	162	168	177	185	193	202
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205	206	213	210	90	225	242	247	257	287	284	286	290	169	162	168	177	185	194
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-142	-192	-15	-20	-258	-324	-144	-237	-388	-29	-114	17	-277	-187	-36	-130	-258	-374	-147
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FOLDOUT FRAME

TABLE 10.3-1) CON'

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2)	170	33	175	181	187	193	199	207	207	226	89	95	101	108	114	120	126	131	150	277	
	-361	-408	-307	-391	-117	-194	-293	-351	-106	-209	-488	-212	-296	-381	-104	-190	-275	-367	-110	-107	
3)	168	167	31	174	180	186	192	200	200	219	87	93	100	106	112	118	123	142	256	276	
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4)	166	165	166	29	172	177	183	191	192	210	85	92	98	104	110	115	134	245	255	276	
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5)	165	163	164	164	27	169	175	183	184	202	84	90	96	102	107	126	235	244	255	275	
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6)	163	161	162	161	161	24	167	175	175	194	82	88	94	99	118	227	235	244	255	275	
	-332	-194	-76	-314	-190	-257	-171	-227	18	-88	-104	-190	-275	-367	-108	-91	-177	-264	8	-86	
7)	161	159	160	159	159	159	23	166	167	186	80	86	91	110	219	227	235	245	255	275	
	-71	-293	-175	-53	-289	-171	-219	-101	-219	46	-190	-275	-367	-108	-92	-177	-263	10	-77	-172	
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	-129	-351	-233	-111	11	-227	-101	-177	-94	-212	-275	-367	-108	-94	-179	-264	10	-76	-163	102	
9)	153	151	152	152	152	151	151	151	151	19	175	75	94	208	215	223	231	239	248	259	279
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	-404	-488	-212	-296	-380	-104	-190	-275	-367	-106	-446	-361	-445	-169	-255	-332	-71	-129	-244	-347	
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FOLDOUT FRAME

TABLE 10.3-1) CONTINUED

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23)	75	88	213	220	228	235	243	252	258	278	151	149	150	150	149	148	150	140	0	155	1		
24)	-137	-33	-223	-307	-31	-114	-202	85	-21	76	-382	-243	-124	-8	-229	-142	62	-254	-7	-27	-1		
25)	73	73	89	215	222	229	238	244	252	265	144	142	144	142	142	144	135	1	140	168	16		
26)	-263	-128	-36	-170	-254	17	-69	-145	85	-207	-140	-361	-247	-113	-17	-192	-132	-251	-254	-57	-24		
27)	73	72	74	89	218	224	233	238	244	256	141	140	140	139	139	141	132	1	135	150	163	16	
28)	-381	-256	-129	-36	-191	-277	-6	-69	-203	-114	-259	-125	-355	-259	-75	-15	-135	-132	62	75			
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30)	-146	-374	-258	-130	-36	-187	-276	17	-115	-29	-387	-238	-144	-324	-258	-20	-15	-192	-142	-11	-11		
31)	74	73	73	72	74	89	218	222	228	239	137	135	138	129	2	130	141	142	149	166	11		
32)	-267	-138	-375	-257	-129	-36	-191	-254	-32	55	-134	-381	-204	-141	-264	-258	-75	-17	-229	-154	-2		
33)	74	73	73	73	72	74	89	215	220	232	134	135	127	2	129	139	139	142	150	165	11		
34)	-390	-260	-141	-376	-257	-130	-36	-171	-308	-219	-281	-453	-386	-148	-141	-324	-259	-113	-8	-268			
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37)	74	73	73	73	73	73	72	73	88	.217	125	2	126	135	135	137	140	142	149	165	11		
38)	-272	-142	-382	-260	-138	-374	-256	-128	-33	-49	-516	-277	-267	-453	-381	-237	-125	-361	-244	-151	-2		
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40)	-403	-272	-153	-390	-267	-147	-382	-263	-138	-47	-521	-517	-342	-282	-135	-388	-260	-141	-383	-289	-3		
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45)	144	142	144	142	142	144	135	1	140	168	73	73	89	215	222	229	238	244	252	265	2		
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TABLE 10.3-1 CONT.

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5 122 131 137 147 155 163 172 179 190 225 214 212 211 210 210 210 211 211 135
 7 -15 -201 36 -98 -238 -14 -147 -288 -71 98 -172 -69 27 -236 -140 -44 -308 -212 -243
 4 23 118 127 136 144 152 161 168 179 206 199 197 195 195 194 195 195 127 122
 5 -182 -99 -228 -7 -144 -281 -54 -195 -338 -172 -83 15 -247 -151 -55 -319 -223 -248 -160
 5 110 21 121 130 138 147 155 163 174 196 189 186 185 184 184 184 119 114 117
 1 -99 -216 -106 -241 -19 -156 -290 -71 -214 -69 15 -244 -147 -51 -315 -219 -247 -160 -409
 3 111 113 24 125 133 142 150 158 169 187 179 177 175 175 175 111 106 109 110
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 5 112 114 117 26 126 134 143 150 161 178 171 168 167 166 103 98 101 102 103
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 214 212 211 210 210 210 211 211 135 15 122 131 137 147 155 163 172 179 190
 -172 -69 27 -236 -140 -44 -308 -212 -243 -127 -15 -201 36 -98 -238 -14 -147 -288 -71
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 -83 15 -247 -151 -55 -319 -223 -248 -160 -15 -182 -99 -228 -7 -144 -281 -54 -195 -338
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FOLDOUT FRAME

TABLE 10.3-11 CONT

21)	63	148	156	163	171	179	188	198	208	217	119	116	117	117	115	115	118	110	109	0
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23)	53	52	62	152	159	167	175	182	188	198	101	98	98	98	99	94	96	2	101	110
24)	53	52	52	62	153	160	168	175	180	188	98	95	96	97	92	94	2	96	99	119
25)	54	52	53	52	62	152	160	167	171	179	96	93	95	91	92	3	94	94	104	115
26)	54	53	52	52	52	62	153	159	164	171	94	93	89	91	4	92	92	99	103	116
27)	55	53	53	53	52	52	62	152	156	163	95	88	91	5	91	91	97	98	103	117
28)	55	53	54	53	52	53	52	62	149	156	89	89	5	91	89	95	96	98	104	117
29)	55	53	53	53	52	52	52	62	148	89	6	89	88	93	93	95	98	103	116	-
30)	56	55	55	55	54	54	53	53	53	64	7	89	89	96	94	96	98	101	106	119
31)	119	116	117	117	115	115	118	110	109	0	63	148	156	163	171	179	188	198	208	217
32)	106	103	104	103	103	104	99	101	1	109	53	62	148	156	164	171	180	188	195	208
33)	101	98	98	98	99	94	96	2	101	110	53	52	62	152	159	167	175	182	188	198
34)	98	95	96	97	92	94	2	96	99	119	53	52	52	62	153	160	168	175	180	188
35)	96	93	95	91	92	3	94	94	104	115	54	52	53	52	62	152	160	167	171	179
36)	94	93	89	91	4	92	92	99	103	116	54	53	52	52	52	62	153	159	164	171
37)	95	88	91	5	91	91	97	98	103	117	55	53	53	53	52	62	152	156	163	-
38)	89	89	5	91	89	95	96	98	104	117	55	53	54	53	52	53	52	62	149	156
39)	89	6	89	88	93	93	95	98	103	116	55	53	53	53	52	52	52	62	148	-
40)	7	89	89	96	94	96	98	101	106	119	56	55	55	55	54	54	53	53	53	64
	-435	-356	-521	-389	-264	-119	-345	-210	-70	-309	-264	-484	-345	-210	-433	-296	-160	-386	-239	-120